CODE CHANGE PROPOSAL

2008 Title 24 Building Energy Efficiency Standards Update

Inclusion of Solar Reflectance and Thermal Emittance Prescriptive Requirements for Residential Roofs in Title 24

(Revised November 27, 2007)

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Overview

Description

The current (2005) Title-24 standards prescribe minimum values of solar reflectance and thermal emittance for low-sloped roofs (i.e., roofs with a ratio of rise to run not exceeding 2:12) on non-residential buildings. This report proposes adding prescriptive requirements for the solar reflectance and thermal emittance of roofs to California's Title-24 standards for residential buildings with steep-sloped roofs (i.e., roofs with a ratio of rise to run exceeding 2:12) and residential buildings with low-sloped roofs.

The proposed measure advocates minimum requirements for the solar reflectance and thermal emittance of roofs to reduce cooling energy usage and peak electrical power demand in air-conditioned buildings regulated by Title 24. Such buildings include but are not limited to single-family dwellings, multifamily dwellings, and mobile homes. Attachment 1 lists building and occupancy types covered by the existing and the proposed standards. Prior research has indicated that savings per unit floor area are greatest for buildings located in climates with long cooling seasons and short heating seasons, particularly those buildings that have distribution ducts in the attic and/or low rates of attic ventilation (Akbari et al., 2005; Akbari and Konopacki 2005; Akbari et al., 1999; Konopacki and Akbari, 1998).

Benefits

Many existing roofing products (e.g., dark-colored fiberglass asphalt shingles) have low solar reflectance (ability to reflect sunlight) and high thermal emittance (ability to radiate heat). Increasing the solar reflectance of a roof without reducing its thermal emittance lowers its surface temperature in the sun.[1] This proposal advocates the prescription of minimum requirements for the solar reflectance and thermal emittance of roofs to reduce their daytime surface temperatures.[2]

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[1] A measure that decreases thermal emittance while increasing solar reflectance (e.g., substitution of a bare metal surface for a non-metallic surface) may or may not reduce the surface temperature of the roof. Virtually all roofing products with nonmetallic surfaces (including painted metals) have high thermal emittance (about 0.80 to 0.90). Under standard summer afternoon conditions (Levinson et al. 2005a), variations in thermal emittance within that range have little effect on roof temperature. For example, decreasing thermal emittance to 0.80 from 0.85 increases the temperature of a roof with solar reflectance 0.55 by about 0.5K. However, a bare metal roofing product can exhibit a very low thermal emittance (about 0.05 to 0.30) that can significantly

Reducing roof temperature decreases heat flow from the roof into the building, which in turn reduces cooling power demand in an air-conditioned building. Because roof temperatures peak in the afternoon, when summer electricity use is highest, reducing roof temperature can also lower peak electricity demand.

Reducing roof temperature decreases the amount of heat transferred to the outdoor air. This would result in lower air temperatures that can slow urban smog formation and increase human health and outdoor comfort. Reducing roof temperature may also increase roof lifetime by reducing thermal stress, lessening maintenance and waste.

Environmental Impact

Lowering roof temperature is expected to have both positive and negative environmental impacts. Benefits include increased human comfort, slowed smog formation, and mitigation of urban heat islands in summer. Waste from disposal of roofs would also decrease. Penalties include slightly higher wintertime heating energy use and degraded wintertime urban air quality because of higher heating energy use.

Environmental Benefits

Reducing roof temperature decreases the amount of heat transferred to the outdoor air. This would result in lower air temperatures that can slow urban smog formation and increase human comfort both outdoors and in unconditioned buildings. On a clear summer afternoon, the air temperature in a typical North American urbanized area can be about 2 to 9ºF hotter than that in the surrounding rural area. The additional air-conditioning use induced by this urban air temperature elevation is responsible for 5 to 10% of urban peak electric demand, at a direct cost of several billion dollars

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increase roof temperature if used to replace a high-emittance product. For example, decreasing thermal emittance to 0.20 from 0.85 increases the temperature of a roof with solar reflectance 0.55 by about 11K.

[2] To maintain an equal temperature under the sun, a surface with low thermal emittance requires a higher solar reflectance than does a surface with high thermal emittance. Under standard summer afternoon conditions, a 4 point (0.04) decrease in thermal emittance has about the same effect on the temperature of a weathered white roof (aged solar reflectance 0.55, aged thermal emittance 0.85) as a 1 point (0.01) decrease in solar reflectance (Levinson et al. 2005a). Hence, we propose a higher minimum aged solar reflectance for surfaces with low aged thermal emittance (less than 0.75) than for surfaces with high aged thermal emittance (not less than 0.75).

annually in the U.S. At the community scale, increasing the solar reflectance of roofs can effectively and inexpensively mitigate an urban heat island (Akbari et al., 2001).

Air temperature also has a significant influence on the formation of urban smog. Measurements and computer simulations of the effect of temperature on Los Angeles smog formation show that a significant reduction in ozone concentration is achieved by lowering the ambient temperature. The simulations predict a reduction in population-weighted smog (ozone) of 10 to 20% resulting from a 3 to 4ºF cooling in ambient temperature. Decreases in roof temperature contribute about one-third of this reduction. For some scenarios, a 10 to 20% reduction in ozone is comparable to that obtained by replacing all gasoline on-road motor vehicles with electric cars (Rosenfeld et al., 1995).

It is also important to note that reduced peak air conditioning load reduces power plant emissions at exactly the time when pollutants of all kinds have the most deleterious impact. This effect—reduced peak power plant emissions--happens independently of the urban heat island phenomenon. Hence, reducing the surface temperature of roofs offers the following three air quality benefits:

- it reduces heat flow from the roof into a conditioned building, decreasing daily and peak air conditioning energy use and power plant emissions;
- it decreases ambient air temperature, reducing daily and peak air conditioning energy use and power plant emissions by decreasing the temperature difference across the building envelope; and
- it reduces ambient air temperature, slowing the temperature-dependent formation of smog.

Lowering roof temperature may also increase roof lifetime by reducing thermal stress. Thus, if applied in the course of either new construction or regularly scheduled roof replacement (i.e., once every 10 to 25 years), measures that reduce roof surface temperature would reduce waste and the need for landfill.

Environmental Penalties

Reducing roof temperature tends to increase consumption of building heating energy. Of particular concern is the potential to increase gas-furnace emissions into local air districts where winter air pollution may be problematic. That is, if a building is cooled with remotely generated electric power, and heated with locally burned natural gas, lowering roof temperature may increase annual local emissions even while reducing annual energy consumption.

There are no requirements by the EPA or the Cool Roof Rating Council (CRRC) to wash roofs. Some manufacturers will void the warranty of a roof if the roof is washed (Miller 2005).

Type of Change

Existing Title 24 Code

California's Title 24 Energy Code, "Building Energy Efficiency Standards for Residential and Non-Residential Buildings," defines a "cool roof" as a "roofing material with high thermal emittance and high solar reflectance, or low thermal emittance and exceptionally high solar reflectance as specified in Section 118 (i) that reduces heat gain through the roof." Title 24 specifies rules for certification and labeling of roofing product solar reflectance and thermal emittance. The 2005 Title 24 Code includes cool roofs in the prescriptive requirements for non-residential building envelopes with low-sloped roofs. For residential buildings, cool roofs are a performance-based compliance option. Section 3.3.7 of the 2005 Residential Compliance Manual states:

> "Compliance credit may be taken when a cool roof is installed when using the performance approach. The credit is available only if there is no radiant barrier installed. In the performance method calculations, the cooling benefit of a cool roof is assumed to be equal to that of a radiant barrier. There is no heating impact calculated for a cool roof (while there is some heating benefit assumed for a radiant barrier).
>
> To be a cool roof material under the Standards, for low-slope roofs (rise to run of 2:12 or less), the material must be rated by the Cool Roof Rating Council (CRRC; www.coolroofs.org), and it must have an initial reflectance rating of at least 0.70 (rated by the CRRC) and an initial emittance of at least 0.75 (rated by the CRRC). There are some exceptions, one being for the more common higher roof slopes for homes: for residential buildings three stories or less (low-rise residential), concrete and clay tile roofs must have an initial reflectance rating of at least 0.40 (rated by the CRRC) and an initial emittance of at least 0.75 (rated by the CRRC). The other exceptions apply to metal roofs and liquid-applied roof coatings. Metal roofs, or any other roof with an initial emittance less than 0.75, must have a minimum initial reflectance determined by an equation given in §118(i)2 of the Standards and here: [$0.70 + 0.34 * (0.75 - \varepsilon_{initial})$]. Liquid-applied coatings are not commonly used on residential buildings, but the Standards allow for them as cool materials for low-slope applications under §118(i)3."

Section 3.2.2 of the 2005 Residential Alternative Calculation Method (ACM) Approval Manual states:

> "*Cool Roofs*
>
> *Proposed Design*. The ACM shall allow the user to input a cool roof. The presence of a cool roof shall be reported in the *Special Features and Modeling Assumptions* listings on the CF-1R.
>
> *Standard Design*. The *Standard Design* shall be modeled without a cool roof."

To model a cool roof, Section 4.2.2 of the 2005 Residential ACM states:

> "*Algorithm*
>
> Cool roofs are modeled to have an impact equal to the cooling savings for radiant barriers. The calculations for cool roofs are the same as radiant barriers, except that $UfacMod_{heating}$ (see Equation R4-8) is assigned a value of 1.00. In the event that both a cool roof and radiant barrier are specified, there is no credit for the cool roof.
>
> *Eligibility Criteria*
>
> Cool roofs shall meet specific eligibility and installation criteria to receive credit for compliance. The solar reflectance shall be 0.4 or higher for tile roofs or 0.7 or higher for other roof materials; and the emittance shall be 0.75 or higher. Liquid applied cool roof products shall meet the requirements of Section 118(i)3 of the standards. All products qualifying for this credit shall be rated and labeled by the Cool Roof Rating Council in accord with Section 10-113 of the standards. The use of a cool roof shall be listed in the *Special Features and Modeling Assumptions* listings of the CF-1R and described in detail in the ACM Compliance Supplement."

Code Change Proposal

In this report, we propose the prescription of minimum values of solar reflectance and thermal emittance of roofs in the 2008 California Title 24 Code for both residential buildings with low-sloped roofs and residential buildings with steep-sloped roofs. In a parallel study, we also propose the prescription for minimum values of solar reflectance and thermal emittance of roofs in the 2008 California Title 24 code for non-residential buildings with steep-sloped roofs.

The proposed change adds a prescriptive requirement based on cost effectiveness that establishes a minimum 3-year-aged thermal emittance and minimum 3-year-aged solar reflectance for roof materials in some of California's 16 climate zones (Figure 1).

For residential buildings with low-sloped roofs in climate zones 10, 11, 13, 15, and 16, we propose that

- any roofing product with a three-year-aged thermal emittance not less than 0.75 shall have a minimum three-year-aged minimum solar reflectance of 0.55; and
- any roofing product with a 3-year aged thermal emittance $\boldsymbol{\varepsilon}_{\mathbf{aged}}$ less than 0.75 shall have a minimum 3-year aged solar reflectance of $0.55 + 0.24* (0.75 - \varepsilon_{aged})$.

No minimum values of solar reflectance or thermal emittance would be prescribed for residential buildings with low-sloped roofs in other climate zones.

For residential buildings with steep-sloped roofs in climate zones 9 through 16, we propose that

- any roofing product with a three-year-aged thermal emittance not less than 0.75 shall have a minimum three-year-aged minimum solar reflectance that varies by roofing material: 0.25 for fiberglass asphalt shingle, and 0.40 for all other roofing products, including but not limited to concrete tile, clay tile, and coated metal; and
- any roofing product with a 3-year aged thermal emittance $\boldsymbol{\varepsilon}_{\mathbf{aged}}$ less than 0.75 shall have a minimum 3-year aged solar reflectance of $0.40 + 0.31 * (0.75 - \varepsilon_{aged})$.

No minimum values of solar reflectance or thermal emittance would be prescribed for residential buildings with steep-sloped roofs in other climate zones.

Roofing products are described in Table 2.

Three-year-aged values of solar reflectance and thermal emittance are determined as follows.

a. If the product's three-year-aged values of solar reflectance and thermal emittance have been certified and labeled by the Cool Roof Rating Council (CRRC), these CRRC-certified and labeled three-year-aged values must be used.

b. If the CRRC has certified and labeled the product's initial values of solar reflectance and thermal emittance, but has not certified and labeled the product's three-year-aged values of solar reflectance and thermal emittance, the product's three-year-aged solar reflectance ρ_{aged} and three-year-aged thermal emittance ε_{aged} are estimated from its CRRC-certified and labeled values of initial solar reflectance $\rho_{initial}$ and initial thermal emittance $\varepsilon_{initial}$ using the following two formulas:

$$\rho_{aged} = 0.2 + 0.7 * (\rho_{initial} - 0.2)$$

$$\varepsilon_{aged} = \varepsilon_{initial}$$

c. If neither three-year-aged nor initial values of the product's solar reflectance and thermal emittance have been certified and labeled by the CRRC, the product will be assigned a default three-year-aged solar reflectance of 0.10 and a default three-year-aged thermal emittance of 0.75.

Requirements for three-year-aged thermal emittance and three-year-aged solar reflectance are based on an estimated life-cycle cost (LCC) analysis for roofs on residential buildings.[3] Requirements are considered cost effective if the life-cycle time-dependent-valuation (TDV) savings were at least $0.20/ft^2 (the maximum expected cost premium for materials meeting the requirements.)

For low-sloped roofs, the use of products with a thermal emittance of 0.85 and a three-year-aged solar reflectance of 0.55 was found to be cost effective in climate zones 10, 11, 13, and 15 with or without a radiant barrier, and in climate zones 8, 9, 12, 14, and 16 without a radiant barrier. Since radiant barriers are required in climate zones 2, 4, and 8 through 15 for residential buildings, minimum three-year-aged values of thermal emittance and solar reflectance are proposed for residential buildings with low-sloped roofs in climates zones 10, 11, 13, 15, and 16. No requirements are proposed for residential buildings with low-sloped roofs in other climate zones.

For steep-sloped roofs, the use of products with a three-year-aged thermal emittance of 0.85 and a three-year-aged solar reflectance of 0.25 for fiberglass asphalt shingle and 0.40 for all other

[3] Our simulations for determination of cost effectiveness assume that both the higher- and lower-reflectance prototype roofs have high thermal emittance (a three-year-aged thermal emittance of 0.85). In those climate zones for which we propose minimum three-year-aged values of solar reflectance and thermal emittance, we suggest requiring a minimum three-year-aged thermal emittance of 0.75, rather than 0.85. We do so because (a) roofing materials usually have either a high thermal emittance (0.80 – 0.90) or a low thermal emittance (0.05 – 0.30); (b) there is an uncertainty of about ±0.05 when measuring thermal emittance; and (c) we wish to avoid disqualification-by-measurement-error of products with high thermal emittance.

products was found to be cost effective in climate zones 9 through 15 with or without a radiant barrier, and in climate zone 16 without a radiant barrier. Since radiant barriers are required in climate zones 2, 4, and 8 through 15 for residential buildings, minimum three-year-aged values of thermal emittance and solar reflectance are proposed for residential buildings with steep-sloped roofs in climates zones 9 through 16. No requirements are proposed for residential buildings with steep-sloped roofs in other climate zones.

Performance approach calculations would result in compliance credits or penalties, depending on the product performance rating relative to the prescriptive requirement.

The proposed change modifies both compliance approaches, as described below. Revisions will be necessary to the Standards, Residential Manual, Residential ACM, and compliance forms to reflect the changes.

Prescriptive Compliance. Adopt the above requirements for three-year-aged values of solar reflectance and thermal emittance of residential building roofs. This would expand the list of prescriptive envelope requirements, since the 2005 revisions to Title 24 do not prescribe minimum values for the solar reflectance and thermal emittance for residential roofs.

Performance Compliance. The 2001 revisions allow the inclusion of roofs with high solar reflectance and high thermal emittance as a compliance option for credit. The current 2005 revisions continue to use a modified form of the radiant barrier algorithms in the Residential ACM (which are reflectance and emittance independent) to determine the energy budget for cool-roof-related performance compliance calculations, resulting in potential compliance credits or penalties, regardless of the product performance rating. The proposed 2008 revisions will use newly established prescriptive requirements for residential buildings with low-sloped roofs and residential buildings with steep-sloped roofs and the newly created attic model (Niles et al. 2006) to determine the energy budget for performance compliance calculations, resulting in potential compliance credits or penalties that depend on the product performance rating relative to the prescriptive requirement.

Technology Measures

Measure Availability and Cost

Technologies

The daytime surface temperature of a roof is raised by absorption of solar radiation and lowered by thermal radiation to the sky. Solar heating is proportional to solar absorptance (absorptance = 1 – reflectance), while radiative cooling is proportional to thermal emittance. Hence, other factors (e.g., incident solar radiation, convective cooling, and conductive cooling) being equal, a roof with high solar reflectance and high thermal emittance can stay cooler than a roof with a low solar reflectance and/or low thermal emittance.

Virtually all construction materials except bare, shiny metals have high thermal emittance. [4] Since 95% of solar radiation arrives at the earth's surface in the visible and near-infrared (NIR) spectra,[5] a roof with a non-metallic surface and high visible and/or NIR reflectance will be cool. Light-colored surfaces are cool because they have high visible reflectance, high NIR reflectance, and high thermal emittance. Dark-colored surfaces colored with conventional (NIR-absorbing) pigments are warm because they have low visible reflectance and low NIR reflectance. A surface with a dark-colored "cool" coating system[6] has low visible reflectance and high NIR reflectance, and is described as a cool color surface. It is cooler than a conventionally pigmented dark-colored surface but warmer than a light-colored surface. Shiny metals typically have high visible and NIR reflectances, but low thermal emittances, and thus stay warmer than a non-metallic surface of comparable solar reflectance. However, a low-emittance surface can stay as cool as a high-emittance surface if the low-emittance surface has a higher solar reflectance. For brevity, the terms reflectance (ρ), absorptance (α), and

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[4] Non-metallic construction materials typically have thermal emittances in the range of 0.80 to 0.95. A bare, shiny metal (e.g., aluminum foil) may have an emittance as low as 0.03, while a roof coating formed with metal flakes may have an intermediate emittance (around 0.50).

[5] 43% of the energy in the standard air-mass 1.5 solar spectrum (300-2,500 nm) lies in the visible range (400-700 nm). Another 52% is in the near-infrared range (700-2,500 nm), and 5% is in the ultraviolet range (300-400 nm).

[6] The top layer in a dark-colored cool coating system is colored with pigments that have high visible absorptance, low NIR absorptance (ability to convert light to heat), and possibly strong NIR backscattering (ability to reverse the direction of light). If the topcoat has weak NIR backscattering, it must be applied over a basecoat with high NIR reflectance (e.g., a white coating), or over a substrate with high NIR reflectance (e.g., zincalume steel, clay tile).

emittance (ε) will be used hereafter to denote solar reflectance, solar absorptance, and thermal emittance, respectively.

Products that are installed on steep-sloped roofs typically include asphalt shingles, concrete tiles, clay tiles, fiber-cement tiles, slate, wood shakes/shingles, architectural metal panels, and individual metal roof components. Products that are typically installed on low-slope surfaces include single-ply membranes, built-up-roofs (BUR), modified bitumen, spray polyurethane foam, roof coatings, and standing-seam profiled metal. Some products that are typically installed on low-slope roofs may also be installed on steep-slope roofs (e.g., single-ply membranes and roof coatings) (EPA, 2006).

As Table 1 shows, there are warmer and cooler options available for nearly all roofing products. Steep-sloped and low-sloped roofing technologies are described in Table 2.

Market

Table 2 lists data from the National Roofing Contractors Association (NRCA 2003) that characterize roofing material shares of the combined residential and commercial 2002 markets in the Pacific region states (California, Oregon, and Washington). For steep-sloped roofs, which accounted for about 50% of sales dollars in these three states, sales were dominated by asphalt shingle (44% new construction, 55% reroofing), tile (21% new construction, 13% reroofing), and metal (18% new construction, 12% reroofing) products[7]. For low-sloped roofs, sales were dominated by single-ply membrane (43% new construction, 34% reroofing), modified bitumen (20% new construction, 24% reroofing), and BUR (17% new construction, 21% reroofing) products.

Western Roofing Insulation and Siding magazine projected that the total roof construction sales in 2005 was $4.7 billion for residential buildings in the 14-state western U.S. market (Western Roofing 2006). California roof sales accounted for 37% ($1.7 billion) of the 14-state combined residential new construction and reroofing markets (personal communication with M. Dodson, 2005)[8]. Three classes of roofing materials — fiberglass asphalt shingles (48%), concrete and clay tiles (27%), and

[7] Title 24 defines “new construction” to include newly constructed buildings, additions to existing buildings, and alterations to existing buildings; however, to be consistent with industry terminology, we use the term “new construction” in this study to refer to the construction of a roof on a new building, and use the term “reroofing” to refer to the replacement of a roof on an existing building.

[8] Product shares in the western-region roofing market are not necessarily representative of those in California.

metal (9%) — collectively accounted for 84% of sales dollars in the western U.S. residential market[9]. Slate (5%), wood shingles/shakes (4%), and other materials made up the remainder. The *Western Roofing* and NRCA data suggest that the majority of residential roofs are steep-sloped.

Using the market share sales data reported by the NRCA, and the relative median material costs listed in Table 1, we estimate that the dominant roof materials based on roof *area* fractions of annual new roof construction and reroofing are fiberglass asphalt shingles (56% of new construction, 66% of reroofing); metal (11% of new construction, 6% of reroofing); and tile (9% new construction, 5% of reroofing); totaling 80% and 83% respectively for of the new construction and reroofing areas. Similarly for the remaining approximately 20% of roof area, we estimate that the dominant materials are liquid applied coatings (11% of new construction, 2% of reroofing); BUR (4% each of new construction and reroofing); and modified bitumen (3% of new construction and 4% of reroofing).

The two aforementioned data sources (NCRA and Western Roofing) describe markets that include but are not limited to California. We have used these data to characterize the California market. Although uncertainties in California market shares resulting from this approximation introduce uncertainty in our state-wide savings estimates, they do not affect our cost effectiveness analysis of increasing the solar reflectance of any particular roofing material.

The Energy Information Agency's Residential Energy Consumption Survey (RECS) lists the distribution of floor area and the distribution of number of stories by building type for California residences (EIA 2001). These data indicate that 54% of the residential buildings in California are single-story and 41% were two-story. Approximately 75% are single-family dwellings; the remainder is primarily one- and two-story multifamily dwellings (24%). Based on these data, assuming that two story residences have a roof area that is half the floor area, and assuming that 80% of the single-family dwellings have a roof slope of at least 3:12, we estimate that the ratio of overall roofing area to floor area is approximately 0.8.

The RECS data also indicate that 5.2 million California households used electric air conditioning in 2001. The household distribution of the fraction of rooms that were air-conditioned is: 3.5 million, 100%; 1 million, 50-99%; 0.4 million, 25-49%; and 0.3 million, 1-24%. Based on this distribution, we estimate that approximately 36% of the California residential floor area is air-conditioned during the summer.

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[9] The 14 western states included in this market are Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Texas, Utah, Washington, and Wyoming.

The California Energy Commission (CEC) estimates that there were about 12.2 million California households in 2005 and that about 0.14 million new residential buildings are added each year. Assuming an average floor area per household of 1,761 ft^2 for single-family dwellings (Gorin 2006), 1,100 ft^2 for a household in multifamily dwellings, and 700 ft^2 for the other types of residential buildings in California, we estimated that the total floor area for California residences was approximately 18.4 billion ft^2 in 2005, with an annual addition of approximately 220 million ft^2 of floor area for new construction. Using the 0.8 ratio of overall roofing area to floor area and the 36% air-conditioning fraction, we estimate that the total roof area for California's air-conditioned residential buildings in 2005 was approximately 5.3 billion ft^2, with an annual addition of about 64 million ft^2 of roofing for residential new construction.

F.W. Dodge (2003) data indicate that the Pacific region accounted for 460 million ft^2 of new roofing and 1,770 million ft^2 of reroofing, yielding a ratio of reroofing area to new roofing area of 3.85. Applying this ratio to the California residential building market, we estimate that the annual reroofing area of air-conditioned residential buildings in California would be about 3.85*64 = 246 million ft^2. The total area of new roofing and reroofing annually for California's air-conditioned residential buildings would therefore be approximately 310 million ft^2.

Assuming that 80% of the residential new construction and reroofing area is steep-sloped, we estimate that the combined annual new roof and reroofing area of air-conditioned California residential buildings with steep-sloped roofs is about 248 million ft^2, while that with low-sloped roofs totals about 62 million ft^2.

Manufacturers

There are over 200 companies manufacturing roofing products in the United States. Most manufacturers specialize by type of roofing material. However, firms that manufacture asphalt-based roofing products, such as asphalt shingles, built-up roofing, and/or modified bitumen, may offer all three. Companies that specialize in asphalt-based roofing have the largest sales volumes.

Table 3 lists major roofing manufacturers and their primary products.

Distribution

Roofing manufacturers sell most of their roofing products through distributors. The distributors generally contact the manufacturers to obtain materials, although some manufacturers also use representatives to sell products.

Though more profitable for the manufacturer, factory-direct sales make up a smaller portion of the roofing market than does distribution, and are usually used only for large-quantity purchases. Manufacturers distribute most of their products through local outlets such as independent wholesale distributors and company-owned distribution centers.

From the distributor, there are three main channels to the end-user: lumber yards (45 to 50% of sales), direct sales to large contractors or home builders (40%), and retail establishments such as home improvement centers and hardware stores (10 to 15%) (Freedonia Group 1997).

Availability

The EPA EnergyStar® roof program lists approximately 180 Roof Product Partners in the U.S. on its web site (EPA 2006). The EPA program allows manufacturers to self-certify their products' performance criteria and does not include a minimum emittance requirement for eligible roofing products.

According to the EPA program, steep-sloped roofs must have an initial solar reflectance that is at least 0.25. Three years after installation under normal conditions, the solar reflectance must be at least 0.15. Low-sloped roofs must have an initial solar reflectance that is at least 0.65. After 3 years, the solar reflectance must be at least 0.50. Each company's roof product warranty for reflective roof products must be equal in all material respects to the product warranty offered by the *same company* for comparable non-reflective roof membrane products. A company that sells *only* reflective roof products must offer a warranty that is equal in all material respects to the standard *industry* warranty for comparable non-reflective roof products.

The Cool Roof Rating Council has rated the initial solar reflectance and initial thermal emittance of about 680 roofing products as of May 2006 (CRRC 2006).

"Cool" products for low-sloped roofs (primarily white single-ply membranes and white elastomeric coatings) are widely available and have been used to meet the 2005 Title 24 prescriptive requirements for minimum levels of solar reflectance and thermal emittance of a low-sloped roof on a nonresidential building.

The "cool" products market for steep-sloped roofs is very young. However, cool color technologies have been demonstrated for clay tile, concrete tile coating, metal, and fiberglass asphalt shingle products, and are commercially available from a limited number of manufacturers (Akbari et al.

2006). We expect that adoption of prescriptive requirements for the solar reflectance and thermal emittance of steep-sloped roofing materials will stimulate wider production.

Cost

Products that meet the aforementioned requirements for three-year-aged solar reflectance (0.55 for low-sloped roofs, 0.25 for fiberglass asphalt shingle steep-sloped roofs, and 0.40 for all other steep-sloped roofs) and three-year-aged thermal emittance (0.75 for all roofs, with allowance made for products that have exceptionally high solar reflectance) are available for most types of low- and steep-sloped roofing. We propose the use of roofs that meet these requirements for new construction and for reroofing in those climate zones for which they are cost effective. In estimating cost effectiveness, we consider only the incremental initial cost of changing the reflectance of the roof from a low value to a high value.

Additional expenditure might be required if a building owner wished to maintain the roof's reflectance at its initial, rather than three-year-aged, value. That additional cost has not been factored into the LCC analysis because the simulated energy savings are based on three-year-aged reflectances that assume no additional maintenance.

Material and labor costs for roofing projects vary from one contractor to another. Table 4 lists estimates of incremental combined costs obtained from interviews of manufacturers, contractors, owners, and specifiers.

Useful Life and Persistence

Roof reflectance may change over time from aging, weathering, and soiling. In a recent study, Cheng and Miller et al (2006) report the effects of exposure on the solar reflectances of steep-sloped roofing products---coated metal, glazed clay tile, and coated concrete tile samples--- at seven sites in California. The fractional reduction in solar reflectance was about 6% over 2.5 years of exposure, and solar reflectance stabilized after about 2 years. The effect of roof slope appears to have more of an effect on lighter color roofs whose solar reflectance exceeds 0.50 and that exhibit visible contamination. However, precipitation and or wind sweeping helps restore most of the initial solar reflectance. The thermal emittance remained invariant with time and location and was therefore not affected by climatic soiling.

A study monitoring the effects of aging and weathering on 10 low-sloped roofs in California found that the reflectance of cool materials with an initial value of 0.70 can decrease by as much as 0.15, mostly within the first year of service (Bretz and Akbari 1997). Another study at LBNL has found similar reflectance degradations for an assortment of single-ply membrane low-sloped roofs sited around the United States (Akbari et al. 2005a; Levinson et al. 2005b). Once the membranes were cleaned, their reflectances approached those of fresh roofing materials.

ASHRAE Standard 90.2 (residential buildings) assigns credits to "cool" roofs with a minimum reflectance of 0.65 (ASHRAE, 2001). However, the credits are calculated based on an aged reflectance of 0.50 (Akbari et al., 1998c).

Lowering roof temperature reduces the thermal stress that results from diurnal temperature change. This is commonly believed to extend product life (Berdahl et al. 2006). However, potential product-lifetime increases have not been factored into cost-effectiveness calculations because long-term studies of this effect are not available.

Performance Verification

The three-year-aged or initial values of solar reflectance and thermal emittance are to be certified and labeled by the CRRC. No additional performance verification or commissioning activities are required to ensure proper installation and performance of roof products.

Cost Effectiveness

Cost effectiveness can be estimated by quantifying three parameters: net present value (NPV) with time dependent valuation (TDV) of net energy savings (annual decrease in space-cooling-related electricity consumption minus annual increase in space-heating-related gas consumption), first cost savings from downsizing cooling equipment (generally applicable to new construction only), and the cost premium for a cool roof. Three other parameters can yield benefits, but are excluded in this determination of cost-effectiveness: expenditure decrease from participation in a load curtailment program, expenditure decrease from participation in a reflective-roof rebate program, and savings in material and labor costs from extended life of roofing materials.

Steep-Sloped Roofs

We simulated buildings with steep-sloped roofs that used lower- and higher-reflectance versions of fiberglass asphalt shingle, concrete tile, and metal products. The lower-reflectance products typify conventional dark roofs, while the higher-reflectance versions typify "cooler" versions of these roofs that meet the proposed requirements for three-year-aged values of solar reflectance and thermal emittance.

All lower-reflectance products were assigned a three-year-aged solar reflectance of 0.10. Higher-reflectance asphalt shingles were assigned a three-year-aged solar reflectance of 0.25, while higher-reflectance concrete tile and metal products were assigned a three-year-aged solar reflectance of 0.40. All products were assigned a three-year-aged thermal emittance of 0.85.[10]

Based on our simulations of lower- and higher-reflectance shingle, concrete tile, and metal steep-sloped residential roofs on a Title-24 prototypical new building (results for all cases and climate zones shown in Figures 2 through 4), we estimate that substituting a higher-reflectance roof for a lower-reflectance roof yields an energy savings (30-year NPV with TDV) ranging from $-0.20 to 1.67/ft^2 of roof area (average $0.33/ft^2) with. Cost savings from downsizing cooling equipment range from $0.01 to 0.10/ft^2 (average $0.04/ft^2). Total savings (equipment + energy) range from $-0.16 to 1.73/ft^2 (average $0.37/ft^2).

Total savings exceeded $0.20/ft^2 for all materials in climate zones 9 through 15 (with or without a radiant barrier), as well as for metal and tile roofs with a radiant barrier in zones 2 and 8, metal roofs with no radiant barrier in zone 7, and all materials with no radiant barrier in zone 16. Since the typical cost premium for a cool roof is $0.20/ft^2 of roof area or less, the higher-reflectance roofs are expected to be cost effective in these zones.

With cost premiums in the range of $0.10 to 0.20/ft^2, higher-reflectance roofs become cost effective in additional climate zones. Higher-reflectance shingle roofs with radiant barriers and cost premiums not exceeding $0.12/ft^2 and $0.16/ft^2 respectively are also expected to be cost effective in zones 2 and 8. Higher-reflectance shingle and tile roofs with no radiant barrier and cost premiums not exceeding $0.10/ft^2 and $0.15/ft^2 respectively are expected to be cost effective in climate zone 7.

With a cost premium of $0.05/ft^2, all higher-reflectance roof materials are cost effective in almost all zones (exceptions are shingle and tile roofs in zones 3 and 5, metal roofs in zones 3 and 5 with radiant barriers, shingle roofs in zone 6 with radiant barriers, and all materials in zone 1).

[10] The thermal emittance of a nonmetallic roof surface (including a painted metal) is typically in the range of 0.80 to 0.90.

Low-Sloped Roofs

We simulated buildings with lower- and higher-reflectance versions of built-up low-sloped roofs. The lower-reflectance version is a conventional gray roof with a three-year-aged solar reflectance of 0.20, while the higher-reflectance version is a white roof with a three-year-aged solar reflectance of 0.55. Both versions were assigned a three-year-aged thermal emittance of 0.85. The higher-reflectance roof meets the proposed requirements for three-year-aged values of solar reflectance and thermal emittance.

Based on our simulations of lower- and higher reflectance versions of built-up low-sloped residential roofs on a Title-24 prototypical new building (results for all cases and climate zones shown in Figures 2 through 4), we estimate that the 30-year NPV of energy savings ranges from \$-0.25 to 0.73/ft^2 of roof area (average \$0.14/ft^2) with time dependent valuation (TDV). Cost savings from downsizing cooling equipment range from \$0.00 to 0.05/ft^2 (average \$0.03/ft^2). Total savings (equipment + energy) range from \$-0.23 to 0.76/ft^2 (average \$0.17/ft^2).

Total savings (30-year NPV with TDV) exceeded \$0.20/ft^2 of roof area in climate zones 10, 11, 13, and 15 (with or without a radiant barrier), as well as for roofs without a radiant barrier in zones 8, 9, 12, 14, and 16. Since the typical cost premium for a higher-reflectance roof is \$0.20/ft^2 of roof area or less, these cool roofs are expected to be cost effective in all air-conditioned residential buildings with steep-sloped roofs in these zones. For a non-air-conditioned building, a higher-reflectance roof will not save cooling energy use and may increase heating energy use (see Figure 2); the annual TDV-weighted heating penalty varies with climate zone and ranges from 0.5 to 12.6 therms/1000 ft^2 of roof area, which is worth \$0.01 to \$0.30/ft^2 of roof area with time dependent valuation.

With cost premiums in the range of \$0.10 to 0.20/ft^2, higher-reflectance roofs become cost effective in additional climate zones. Higher-reflectance roofs with radiant barriers and cost premiums not exceeding \$0.16/ft^2 (zone 9), \$0.14/ft^2 (zone 12), and \$0.19/ft^2 (zone 14) are expected to be cost effective. Higher-reflectance roofs without a radiant barrier and cost premiums not exceeding \$0.17/ft^2 (zone 2) and \$0.11/ft^2 (zone 7) are also expected to be cost effective.

With a cost premium of \$0.05/ft^2, all higher-reflectance roofs without radiant barriers are cost effective in almost all zones (exceptions are zones 1, 3 and 5), and higher-reflectance roofs with radiant barriers become cost effective in zone 8.

Analysis Tool

The building energy simulation program MICROPAS (Enercomp 2005) was the primary analysis tool used to quantify energy savings and peak demand. We used two versions of MICROPAS: 7.21p for steep-sloped roofs, and 7.25p for low-sloped roofs.[11] Both versions include a major improvement in energy calculation algorithms. MICROPAS can now model the complex convective and radiant heat transfer processes that are characteristic of attics containing ducts (Niles 2006). MICROPAS has other merits: it is based on known and published heat transfer algorithms; just prior to the addition of the attic model, it was certified as an alternative calculation method for use in 2005 Title 24 residential performance-based compliance analyses; and it has since been validated for many test cases, lending confidence to its use.

Relationship to Other Measures

Reducing roof temperature can permit downsizing of cooling and air-handling equipment.

- Reducing roof temperature could reduce the peak building cooling load by 0.1 to 0.6 W/ft^2 of roof area, depending on building type, roof insulation, and climate zone. Hence, the cooling unit can potentially be downsized.
- A building's air-handling unit (AHU) is typically designed to accommodate the summer peak cooling load. A lower summer peak cooling load can reduce the size of the AHU and save electricity. The smaller AHU can also operate more efficiently and use less electricity during the heating season.

Reducing roof temperature may also permit downsizing of roof and ceiling insulation[12].

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[11] Version 7.25p can model flat roofs and steep-slope roofs; version 7.21p models only steep-slope roofs. The two versions produce the same results for steep-slope roofs. Version 7.25p was not available when the steep-slope simulations were carried out.

[12] Reducing roof temperature can also reduce the need for roof and ceiling insulation for an energy neutral case. When a building is cooled, the energy savings yielded by reducing roof temperature are inversely proportional to the level of insulation. At the current prescriptive requirements, total building energy use is reduced by reducing roof temperature, and this installation is cost effective (Akbari et al., 1998).

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Methodology

Overview

The cost effectiveness of minimum requirements for the solar reflectance and thermal emittance of roofs was estimated by comparing the cost premiums and cost savings associated with substituting roofing products of higher solar reflectance for roofing products of lower solar reflectance. Premiums were based on interviews of manufacturers, contractors, owners, and specifiers, while savings were estimated using building energy simulations. The MICROPAS building energy model was used to estimate the effect increasing roof solar reflectance on space cooling and heating energy use by a prototypical Title-24 compliant residential building for each of California's 16 climate zones. Finally, the simulated savings (normalized per 1000 ft^2 of higher-reflectance roof area) were combined with projections of annual new roof and reroofing area additions to predict statewide savings.

Simulated Building Energy Savings

For each of the 448 variations of the prototypical house that we simulated (16 climate zones, three steep-slope roofing materials, one low-slope roofing material, two solar reflectances, two ceiling insulation installation qualities for steep-sloped roofs, with and without a radiant barrier), MICROPAS estimated annual source and 30-year TDV-weighted space cooling electricity use and space heating natural gas use, as well as peak space cooling power demand.

The prototype house is a non-directional two-story single-family dwelling that has been used in previous analyses of changes proposed for the Title 24 Standards (Enercomp 2005). It has a conditioned floor area of 1,761 ft^2, and a ceiling area of 1,261 ft^2. The steep-sloped hip roof has a slope of 5:12; the low-sloped roof is flat. Attic end walls for the flat roof are 30" high.

As prescribed by Package D in the 2005 Title 24 Residential Energy Efficiency Standards, space conditioning is provided by a SEER 13 split-system air-conditioner and a 78% AFUE natural gas furnace. This space conditioning system was modeled with “sealed” supply and return air ducts located in the attic (4% leakage for each of the supply and return duct sections). The ducts were insulated as prescribed by Package D.

The building envelope characteristics are based on Package D. The insulation on top of the ceiling for the steep-sloped roof is R-30 in zones 2 through 10 and R-38 elsewhere; the same insulation amounts are used for the flat roof, but the insulation is located on top of the roof deck instead of at the ceiling. The exterior wall insulation is R-13 in zones 2 through 10, R-19 in zones 11 through 13, and R-21 elsewhere. Fenestration (20% window area to gross wall area ratio) is distributed equally on all four sides of the building. The specific leakage area (SLA) of the envelope is 4.9, which is the default value in the ACM for a “standard” residential building that has not been tested using a blower door.

For the steep-sloped roofs, two ceiling insulation cases were simulated for every climate zone: “standard” insulation as defined in Section 4.2.4 of the 2005 Residential ACM, which accounts for insulation installation quality problems by increasing the overall heat conductance of the ceiling assembly; and “improved” insulation, also as defined in the Residential ACM.[13] Because insulation was not located at the ceiling for the flat-roofed attic and this attic was unvented, we did not simulate ceiling insulation installation quality for the flat roof cases.

For the steep-sloped roofs, two attic configuration cases were also simulated for every climate zone and insulation installation case: one with “conventional” attic ventilation and without a radiant barrier (ε=0.90; 1:150 net venting area to attic floor area ratio, with vents located at the soffits), and one with a radiant barrier (ε=0.05; same venting/floor area ratio, but 70% of the vents are located at

[13] Reducing roof temperature can also reduce the need for roof and ceiling insulation for an energy neutral case. When a building is cooled, the energy savings yielded by reducing roof temperature are inversely proportional to the level of insulation.

the soffits and the remainder at the ridge). We also simulated the flat-roofed attics with and without a radiant barrier, but with no attic venting.

Four different roofing materials were simulated: fiberglass asphalt shingles, concrete tiles, and standing-seam metal panels for steep-slope roofs; and built-up roofing for the flat roofs. We expect that the thermal performance of a building with a clay tile roof is similar to that of a building with a concrete tile roof. The properties of the roof assemblies were as follows:

Asphalt Shingle Roof

Overlapping asphalt shingles are installed (nominally two layers thick) directly over one layer of No. 15 asphalt-saturated roofing felt, all over nominal 1/2" plywood.

The shingle characteristics are based on an average derived from data for two commercially available products (shingles A and B), which have dimensions of 13-1/4" x 39-3/8". The manufacturer's installation manual calls for a 5-5/8" exposure. Our measurements of a product sample indicate that the shingles are about 0.10 in thick (shingle A) and 0.12 in thick (shingle B), which means that the average installed thickness of the overlapped shingle "layer" is about 0.26 in. Our measurements also indicate that a bundle weighs about 64 lb and we counted 22 shingles (shingle A) and 16 shingles (shingle B) in each bundle, which equates to about 3 and 4 bundles respectively installed per roofing square (100 ft^2). The dimensions and weight suggest a shingle density of about 95 lb/ft^3 (shingle A) and 112 lb/ft^3 (shingle B), which is greater than the 2005 ASHRAE Handbook of Fundamentals value for asphalt shingles (70 lb/ft^3), and suggest an installed weight per square of about 190 lb (shingle A) and 260 lb (shingle B). The installed weight per square is consistent with information listed on a GAF Master Elite Contractor's website (VRI 2006). The 2005 Title 24 Joint Appendix and 2005 ASHRAE Handbook of Fundamentals list the thermal resistance and specific heat (C_p) of shingles (presumably for the entire layer of installed shingles) as R-0.44 and 0.30 Btu/(lb-°F) respectively.

Our recent measurements of a sample of a commercially available No. 15 asphalt-saturated roofing felt indicate that it is 0.03 in thick and a 432 ft^2 roll weighs about 53 lb. The dimensions and weight suggest a saturated felt density of about 49 lb/ft^3 (no density listed by ASHRAE), and an installed weight per square of about 12 lb (ignoring the 2 in overlap of adjacent sheets). The 2005 Title 24 Joint Appendix and 2005 ASHRAE Handbook of Fundamentals list the thermal resistance for building paper and permeable felt respectively as R-0.06. No specific heat data are listed, and likely are not important for the simulations (the saturated felt is very light compared to the shingles above and plywood below).

The nominal 1/2" thick plywood sheathing is assumed to actually be 15/32" thick (sanded thickness). The 2005 Title 24 Joint Appendix and 2005 ASHRAE Handbook of Fundamentals list the thermal resistance, density, and specific heat of nominal 1/2" plywood as R-0.62 (the Joint Appendix states R-0.63), 34 lb/ft^3, and 0.29 Btu/(lb-ºF) respectively. The corresponding installed weight per square is 133 lb. We assumed that the saturated felt and plywood can be modeled as a single R-0.68, 34 lb/ft^3, 0.29 Btu/(lb-ºF) layer.

Concrete Tile Roof

Overlapping, flat, lightweight concrete tiles are installed on horizontal nominal 1" x 2" wood battens (actually 3/4" x 1-1/2") over two layers of overlapped No. 30 asphalt-saturated roofing felt, all over nominal 1/2" plywood.

The tiles are based on a commercially available product, which is listed as 16-1/2" x 13" with a 1-1/4" side overlock and nailing holes 1-1/2" from the tile top. The installation manual calls for a 3" head lap. Published specifications for weight are 596 lb per square (lightweight tiles) and about 88 tiles installed per square. We assumed that the tiles are 1/2" thick (not critical because the resistance of the tiles is low compared to the rest of the roof deck resistance). The dimensions and weight suggest a tile density of about 120 lb/ft^3 (consistent with 2005 ASHRAE Handbook of Fundamentals values for lightweight concrete). The 2005 ASHRAE Handbook of Fundamentals lists the thermal resistance of lightweight concrete as R-0.11 to R-0.16 per inch. This means that the 1/2" tile is about R-0.08. The specific heat listed in the 2005 ASHRAE Handbook of Fundamentals for lightweight concrete is 0.20 Btu/(lb-ºF).

We calculated the thermal resistance of the layer comprised of battens and the airspace between the tiles and roof deck using a parallel heat flow path method and assuming a 1/2" to 3/4" thick airspace at a 45 degree slope (averaged values for heat flow up and down cases). Thermal resistance data for the airspace and wood battens are from the 2005 ASHRAE Handbook of Fundamentals. The effective thermal resistance for the batten-airspace layer is R-0.99.

Our recent measurements of a sample of a commercially available No. 30 asphalt-saturated roofing felt indicate that it is 0.057 in thick and a 216 ft^2 roll weighs about 52 lb. The dimensions and weight suggest a saturated felt density of about 50 lb/ft^3 (no density listed by ASHRAE), and an installed weight per square of about 48 lb (24 lb per layer). The 2005 Title 24 Joint Appendix and 2005 ASHRAE Handbook of Fundamentals list the thermal resistance for building paper and permeable felt respectively as R-0.06. We assumed that one layer of No. 30 felt is double this value, which means two layers of No. 30 felt is about R-0.24. No specific heat data are listed, and likely are not important for the simulations.

The nominal 1/2" thick plywood sheathing characteristics are described above for the shingle roof (R-0.62). We assumed that the saturated felt and plywood can be modeled as a single R-0.86, 34 lb/ft^3, 0.29 Btu/(lb-ºF) layer. The felt mass (48 lb/square) is not trivial compared to the plywood (133 lb/square), but probably is not important thermally other than it introduces a slight dampening and time lag in the heat transfer.

Standing-Seam Architectural Metal Roof

Non-overlapped, standing-seam architectural galvanized steel panels are installed directly over one layer of rosin-sized paper (slip sheet) and one layer of No. 30 asphalt-saturated roofing felt, all over nominal 1/2" plywood.

The metal panel thickness is based on a commercially available G-90 galvanized steel panel, which has a standard thickness of 0.025 in (24 ga, US Standard Gauge). The 2005 ASHRAE Handbook of Fundamentals lists mild steel as 489 lb/ft^3. We expect that the very thin layer of zinc on each side of the panel (0.9 oz/ft^2) probably will not change this density by more than about 10%. Together, the thickness and density suggest an installed weight per square of about 103 lb. This weight with a 10% increase for the zinc coating (total of 113 lb) is consistent with information in the 2003 NRCA Roofing and Waterproofing Manual, which lists 24 ga galvanized steel as 116 lb/square. The 2005 ASHRAE Handbook of Fundamentals lists the thermal conductivity and specific heat of mild steel as 26.2 Btu/(h-ft-ºF) and 0.30 Btu/(lb-ºF) respectively. The corresponding thermal resistance is R-(8×10^{-5}).

One manufacturer lists red-rosin paper as 14 lb per 501 ft^2 roll. The 2005 ASHRAE Handbook of Fundamentals lists paper as 58 lb/ft^3, which together with the area and weight per roll suggest a thickness of 0.006 in. and an installed weight per square of 3 lb. The 2005 ASHRAE Handbook of Fundamentals also lists the thermal conductivity and specific heat of paper as 0.075 Btu/(h-ft-ºF) and 0.32 Btu/(lb-ºF) respectively. The corresponding thermal resistance is R-0.007.

No. 30 saturated felt characteristics are described above for the tile roof (only one layer though for the metal roof; R-0.12) and nominal 1/2" thick plywood sheathing characteristics are described above for the shingle roof (R-0.62). We assumed that the rosin-sized paper, felt, and plywood can be modeled as a single R-0.75, 34 lb/ft^3, 0.29 Btu/(lb-ºF) layer.

__Built-Up Roof__

A multiple-ply built-up roof is installed directly over rigid insulation, all over nominal 1/2" plywood.

The built-up roof characteristics are based on values listed in the 2005 Title 24 Joint Appendix and the 2005 ASHRAE Handbook of Fundamentals: thickness of 0.375 in., density of 70 lb/ft^3, thermal resistance of 0.33 (h-ft-ºF)/Btu, and specific heat of 0.35 Btu/(lb-ºF).

For the insulation layer, MICROPAS only requires that the insulation thermal resistance be specified. We used the appropriate values for each climate zone: R-30 in zones 2 through 10 and R-38 elsewhere.

The nominal 1/2" thick plywood sheathing characteristics are described above for the shingle roof (R-0.62).

In each case, annual energy and peak power savings were determined by simulating the building twice: once with a higher-reflectance roof (ρ=0.25 for shingle steep-sloped roofs, ρ=0.40 for concrete tile and metal steep-sloped roofs, and ρ=0.55 for built-up low-sloped roofs), and once with a lower reflectance roof (ρ=0.10 for shingle, concrete tile, and metal steep-sloped roofs; and ρ=0.20 for built-up low-sloped roofs). This corresponds to a solar reflectance difference of $\Delta\rho_0$ = 0.15 for shingle roofs, 0.30 for concrete tile and metal roofs, and 0.35 for built-up roofs, with unchanged thermal emittance (ε =0.85 for all cases).[14] Because savings are linearly proportional to the change in roof solar reflectance (Akbari et al., 1998), savings for some other solar reflectance difference $\Delta\rho_1$ can be calculated from:

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[14] The thermal emittance of a nonmetallic roofing surface (including a painted metal) is typically in the range of 0.80 to 0.90.

$$\text{savings}_{\Delta\rho_1} = \left(\Delta\rho_1 / \Delta\rho_0\right) \times \text{savings}_{\Delta\rho_0}$$

The net present value (NPV) of savings ($/1000 ft^2 of roof area) was calculated with time dependent valuation (TDV) of savings. The TDV method assigns 30-year unit values of NPV to electricity ($/kWh) and natural gas ($/therm) that vary with hour of year and climate zone. These hourly multipliers are used to calculate the NPV of savings achieved in each of the 8760 hours in a year. Summing these hourly savings yields the TDV NPV ($) (Energy and Environmental Economics 2006).

In our analyses, equipment cost savings were added to energy savings to determine total savings. To determine the “purchased” equipment savings associated increasing roof reflectance, the estimated peak demand savings need to be converted to equipment capacity savings at rating conditions. For an air-conditioner, the energy-efficiency ratio (EER) is the equipment capacity (evaporator output, Btu/h) divided by the electrical power input (Watts) for the condensing unit and evaporator fan. For an air-conditioner with a rated EER of 10 (COP 2.9), 1 ton of evaporator output (12,000 Btu/h) corresponds to 1.2 kW of power input. At peak, higher outdoor temperatures than rating conditions can reduce the EER and capacity of the system. For example, in a hot climate like zone 15, our MICROPAS simulations indicate that the EER for the SEER 13 system that we simulated is about 6 at peak and the evaporator capacity is about 10% less than at rating conditions. This means that the evaporator output is reduced to 0.9 ton, which requires about 1.8 kW of power with an EER of 6. Conversely, a nominal 1 kW peak input power saving with an EER of 6 is a 6,000 Btu/h peak output saving, which is a 6,667 Btu/h (0.6 ton) rated capacity requirement reduction including the 10% capacity loss between rating and peak conditions.

For a split-system air-conditioner, RS Means (2006) suggests a $1,650/ton increase for a 3 to 4 ton rated capacity increase and a $550/ton increase for a 4 to 5 ton increase. Conservatively using $550/ton capacity as the rated capacity increase cost premium, an EER reduction to 6 at peak, and a capacity loss of 10% at peak, 1 kW of peak input power savings is worth: [(1 kW x 1000 W/kW) x EER 6 Btu/Wh / 0.9) x [$550/ton / 12,000 Btu/(ton-h)] = $306. Higher EERs and less capacity loss at peak would result in larger cost savings.

Measured Building Energy Savings

Many studies have measured daily air conditioner energy savings and peak power demand reduction from increased roof solar reflectance on residential and non-residential buildings in several warm-weather climates, including California, Florida, and Texas (Miller et al. 2006, Parker et al. 1998, Akbari et al. 1997). Daily energy savings measured after increasing roof reflectance were annualized by multiplying daily savings (kWh/day) by the number of cooling days per year. Energy and peak-demand savings were also lowered to account for reflectance reduction resulting from roof weathering. Degraded annual energy savings (kWh) and peak demand reduction (kW) were normalized per 1000 ft^2 of roof area for comparison with simulated results (kWh/1000 ft^2 and kW/1000 ft^2). This study uses the measured data as practical evidence that increasing roof reflectance provides energy and peak power savings, but relies solely on MICROPAS simulation results for the cost-effectiveness analysis.

Projected Statewide Savings for Cool Residential New Roofs and Reroofing

If the annual savings (energy, demand, or $) per unit roof area in climate zone i is S_i, and the total floor area of residential new buildings in climate zone i is A_i, then the statewide savings can be estimated as:

$$\text{State-Wide Savings} = C \times \text{Sum of } (S_i \times A_i), \text{ for } i = 1 \text{ to } 16.$$

The savings S_i are the combined estimated savings for each roof material type applied in a climate zone, with the savings for each material type (shingles, tile, and metal) weighted by the corresponding fraction of roof area that uses that material type. The coefficient C translates floor area to roof area. The material fractions and coefficient C are based on the data described earlier in the “Market” section of this report. Data that we obtained from the CEC (Gorin 2006) describe the number distribution of residential households by climate zone, and were used to estimate and define A_i. Dividing A_i for each zone by the total floor area defines the “Roof Area Fractions” listed in Tables 6 and 7.

Results

Simulated Building Energy Savings for New Construction

Simulated savings in each climate zone for each of the 12 steep-slope scenarios (three roofing materials, two ceiling insulation installation qualities, with and without a radiant barrier) and two low-slope scenarios (built-up roofing, with and without a radiant barrier) are illustrated in Figures 2 through 4. The following summarizes those results for all 14 scenarios and all 16 climate zones[15]:

- **Annual space-cooling-related TDV-weighted electricity savings:**

Data: Figures 2a-n			Savings (kWh/1000 ft²)		
Roof Slope	Radiant Barrier	Insulation Quality	Min	Max	Average
Steep	No	Standard	14	2,102	647
		Improved	12	2,021	615
	Yes	Standard	6	1,354	409
		Improved	4	1,303	390
Low	No	N/A	6	966	500
	Yes	N/A	6	587	282

- **Annual space-heating-related TDV-weighted natural gas deficits**:

Data: Figures 2a-n			Deficit (therm/1000 ft²)		
Roof Slope	Radiant Barrier	Insulation Quality	Min	Max	Average
Steep	No	Standard	0.9	12.6	5.1
		Improved	0.8	11.2	4.4
	Yes	Standard	0.6	7.3	3.4
		Improved	0.5	6.4	2.9
Low	No	N/A	2.5	12.3	7.5
	Yes	N/A	2.5	10.9	7.1

[15] The minimums, maximums, and averages of TDV-weighted values per 1000 ft² of roof area summarized here represent the range of values for "individual" houses and are not weighted based on roof area distributions and material type distributions throughout California. Statewide saving estimates, which are described later in the report, provide weighting based on roof area distributions and material type distributions.

- **Annual total TDV-weighted net source energy savings:**

Data: Figures 2a-n			Savings (MBtu/1000 ft²)		
Roof Slope	Radiant Barrier	Insulation Quality	Min	Max	Average
Steep	No	Standard	-0.83	6.97	1.70
		Improved	-0.66	6.73	1.66
	Yes	Standard	-0.61	4.49	1.05
		Improved	-0.49	4.34	1.04
Low	No	N/A	-1.03	3.05	0.95
	Yes	N/A	-0.98	1.75	0.25

- **Peak power demand savings:**

Data: Figures 3a-n			Savings (kW/1000 ft²)		
Roof Slope	Radiant Barrier	Insulation Quality	Min	Max	Average
Steep	No	Standard	0.05	0.34	0.17
		Improved	0.05	0.33	0.16
	Yes	Standard	0.04	0.22	0.12
		Improved	0.03	0.21	0.11
Low	No	N/A	0.07	0.17	0.11
	Yes	N/A	0.00	0.09	0.06

- **Cooling equipment cost savings:**

Data: Figures 4a-n (Equip+Energy - Energy)			Savings ($equip/1000 ft²)		
Roof Slope	Radiant Barrier	Insulation Quality	Min	Max	Average
Steep	No	Standard	17	104	52
		Improved	16	101	50
	Yes	Standard	11	66	36
		Improved	10	63	35
Low	No	N/A	22	51	33
	Yes	N/A	-1	28	17

- **Thirty-year net present value TDV-weighted energy savings:**

Data: Figures 4a-n			Savings ($/1000 ft²)		
Roof Slope	Radiant Barrier	Insulation Quality	Min	Max	Average
Steep	No	Standard	-199	1,666	405
		Improved	-158	1,607	396
	Yes	Standard	-146	1,073	251
		Improved	-117	1,036	248
Low	No	N/A	-245	728	228
	Yes	N/A	-234	418	60

- **Total savings (equipment cost savings + 30-year NPV TDV-weighted energy savings):**

Data: Figures 4a-n			Savings ($/1000 ft²)		
Roof Slope	Radiant Barrier	Insulation Quality	Min	Max	Average
Steep	No	Standard	-162	1,729	457
		Improved	-124	1,668	446
	Yes	Standard	-123	1,120	287
		Improved	-96	1,082	283
Low	No	N/A	-223	762	261
	Yes	N/A	-235	435	78

The largest annual savings occurred in the hot southern inland areas (climate zones 10, 13, 14, and 15). The smallest savings were found along the cooler north and central coast (zones 1, 3, and 5), and in the mountains (zone 16).

Source energy savings are not shown in Figures 2 through 4. To facilitate comparisons of simulated energy saving predictions with measured savings, the following summarizes the source energy savings for all 14 scenarios and all 16 climate zones:

- **Annual space-cooling-related source electricity savings:**

			Savings (kWh/1000 ft²)		
Roof Slope	Radiant Barrier	Insulation Quality	Min	Max	Average
Steep	No	Standard	4	928	220
		Improved	3	888	208
	Yes	Standard	2	582	138
		Improved	2	558	131
Low	No	N/A	2	469	182
	Yes	N/A	3	310	107

- **Annual space-heating-related source natural gas deficits**:

			Deficit (therm/1000 ft²)		
Roof Slope	Radiant Barrier	Insulation Quality	Min	Max	Average
Steep	No	Standard	0.6	8.0	3.3
		Improved	0.5	7.1	2.8
	Yes	Standard	0.4	4.7	2.2
		Improved	0.3	4.1	1.8
Low	No	N/A	1.5	7.8	4.8
	Yes	N/A	1.6	7.0	4.5

- **Annual net source energy savings:**

			Savings (MBtu/1000 ft²)		
Roof Slope	Radiant Barrier	Insulation Quality	Min	Max	Average
Steep	No	Standard	-0.59	3.05	0.43
		Improved	-0.48	2.92	0.43
	Yes	Standard	-0.42	1.91	0.25
		Improved	-0.34	1.84	0.26
Low	No	N/A	-0.69	1.45	0.14
	Yes	N/A	-0.65	0.89	-0.09

Measured Building Energy Savings

Increasing the solar reflectance of residential roofs typically yielded measured summertime daily air conditioning savings and peak demand reductions of 10 to 30%, though values have been as low as 2% and as high as 40%. For example:

- In a recent study, Miller et al. (2006) measured the effect of increasing the roof solar reflectance using three pairs of houses with metal, concrete tile, and shingle roofs. The average heat flows through the roof deck dropped by 20% for tile, by 32% for metal and by 30% for asphalt shingle roofs as compared to lower-reflectance conventional roofs. Cooling energy use decreased by about 10-13% for all three types. The savings resulted from increasing the solar reflectance of the tile roof from 0.10 to 0.40, increasing the solar reflectance of the metal roof from 0.08 to 0.31, and increasing the solar reflectance of the shingle roof from 0.09 to 0.26.
- Parker et al. (1998a) measured an average daily energy savings of 7.7 kWh per house (19%) and peak power reduction of 0.55kW (22%) in 11 houses in Florida. The daily electricity savings in individual houses ranged from 0.9 kWh (0.2%) to 15.4 kWh (45%) and the peak power reduction ranged from 0.2 kW (12%) to 0.99 kW (23%). The savings resulted from increasing the solar reflectance of the shingle roofs from 0.08 to 0.70[16].
- Akbari et al. (1997) measured seasonal energy savings of 2.2 kWh/day (80%) and peak demand savings of 0.6 kW (30%) in a 1,700 ft^2 house in Sacramento. The savings resulted from increasing the solar reflectance of the roofs from 0.18 to 0.70.

Statewide Projected Savings for New Construction

Assuming a cost-premium of $0.20/$ft^2$ for each roofing material with increased solar reflectance, the projected state-wide combined savings from increased roof solar reflectance for new construction with attic radiant barriers in climate zones 2, 4, and 8 through 15 and no radiant barriers in other climate zones are:

- annual TDV electricity savings of 14 GWh;
- annual TDV natural gas deficit of 99 ktherm;
- annual TDV net source energy savings of 37 GBtu;
- annual peak power demand savings[17] of 3.2 MW;

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[16] Coating of the shingles initially increased the solar reflectance of the roofs to 0.70. Parker et al. (1998a) do not report the reflectance of the roof at the end of monitoring project. We speculate that the initial solar reflectance would age to 0.55.

[17] "Annual" power savings refer to reductions in the annual need for power plant construction.

- annual equipment savings of $1.0M;
- TDV NPV energy savings of $8.9M;
- total savings (equipment + TDV NPV energy) of $9.9M.

Statewide Projected Savings including Roof Replacement

Assuming a cost-premium of $0.20/ft^2 for each roofing material with increased solar reflectance, the projected state-wide combined savings from increased roof solar reflectance for combined roof replacement and new construction with attic radiant barriers in climate zones 2, 4, and 8 through 15 and no radiant barriers in other climate zones are:

- annual TDV electricity savings of 65 GWh;
- annual TDV natural gas deficit of 465 ktherm;
- annual TDV net source energy savings of 175 GBtu;
- annual peak power demand savings of 15 MW;
- annual equipment savings of $4.6M;
- TDV NPV energy savings of $42M;
- total savings (equipment + TDV NPV energy) of $46M.

Recommendations

Proposed Standards Language

See Attachment 2 (Proposed Standards Language: Solar Reflectance and Thermal Emittance of Residential and Nonresidential Roofs 2008).

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Table 1. Warmer and cooler options for low- and steep-sloped roofs. Shown are ranges of typical values for initial solar reflectance, initial thermal emittance, and estimated material plus labor cost.

Warmer Roof Options				Cooler Roof Options			
Roof Type	*Reflectance*	*Emittance*	*Cost ($/ft²)*	*Roof Type*	*Reflectance*	*Emittance*	*Cost ($/ft²)*
Built-up Roof			1.2 – 2.1	Built-up Roof			1.2 – 2.15
with dark gravel	0.08 – 0.15	0.80 – 0.90		with white gravel	0.30 – 0.50	0.80 – 0.90	
with smooth asphalt surface	0.04 – 0.05	0.80 – 0.90		with gravel and cementitious coating	0.50 – 0.70	0.80 – 0.90	
with aluminum coating	0.25 – 0.60	0.20 – 0.50		smooth surface with white roof coating	0.75 – 0.85	0.80 – 0.90	
Single-Ply Membrane			1.0 – 2.0	Single-Ply Membrane			1.0 – 2.05
black (PVC)	0.04 – 0.05	0.80 – 0.90		white (PVC)	0.70 – 0.78	0.80 – 0.90	
				color with cool pigments	0.40 – 0.60	0.80 – 0.90	
Modified Bitumen			1.5 – 1.9	Modified Bitumen			1.5 – 1.95
with mineral surface capsheet (SBS, APP)	0.10 – 0.20	0.80 – 0.90		white coating over a mineral surface (SBS, APP)	0.60 – 0.75	0.80 – 0.90	
Metal Roof			1.8 – 3.7	Metal Roof			1.8 – 3.75
unpainted, corrugated	0.30 – 0.50	0.05 – 0.30		white painted	0.60 – 0.70	0.80 – 0.90	
dark-painted, corrugated	0.05 – 0.08	0.80 – 0.90		color with cool pigments	0.40 – 0.70	0.80 – 0.90	
Asphalt Shingle			0.5 – 2	Asphalt Shingle			0.6 - 2.1
black or dark brown with conventional pigments	0.04 – 0.15	0.80 – 0.90		“white” (actually light gray)	0.25 – 0.27	0.80 – 0.90	
				medium gray or brown with cool pigments	0.25 – 0.27	0.80 – 0.90	
Liquid Applied Coating			0.5 – 0.7	Liquid Applied Coating			0.6 – 0.8
smooth black	0.04 - 0.05	0.80 – 0.90		smooth white	0.70 – 0.85	0.80 – 0.90	
				smooth off-white	0.40 – 0.60	0.80 – 0.90	
				rough white	0.50 – 0.60	0.80 – 0.90	
Concrete Tile			1 - 6	Concrete Tile			1 - 6
dark color with conventional pigments	0.05 – 0.35	0.80 – 0.90		color with cool pigments	0.40 – 0.50	0.80 – 0.90	
				white	0.70	0.80 – 0.90	
Clay Tile			3 -5	Clay Tile			3 - 5
dark color with conventional pigments	0.20	0.80 – 0.90		terracotta (unglazed red tile)	0.40	0.80 – 0.90	
				color with cool pigments	0.40 – 0.60	0.80 – 0.90	
				white	0.70	0.80 – 0.90	
Wood Shake			0.5 - 2	Wood Shake			0.5 - 2
painted dark color with conventional pigments	0.05 – 0.35	0.80 – 0.90		bare	0.40 – 0.55	0.80 – 0.90	

- Source:
  - 2002 PG&E report, 2005 Title 24 Building Energy Efficiency Standards Update - Inclusion of Cool Roofs in Nonresidential Title 24 Prescriptive Requirements
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Table 2. Low- and steep-sloped roofing technologies and their market shares in Pacific Region (NRCA, 2002-2003)

			PACIFIC[b] (steep-sloped)		PACIFIC[b] (low-sloped)	
Material	Description	Median Cost[a] ($/ft^2)	New Sales	Reroof Sales	New Sales	Reroof Sales
Built-Up Roof (BUR)	A continuous, semi-flexible multi-ply roof membrane, consisting of plies (layers) of saturated felts, coated felts, fabric, or mats, between which alternate layers of bitumen are applied. (Bitumen is a tarlike hydrocarbon mixture often including nonmetallic hydrocarbon derivatives; it may be obtained naturally or from the residue of heat-refining natural substances such as petroleum.) Built-up roof membranes are typically surfaced with roof aggregate and bitumen, a liquid-applied coating, or a granule-surfaced cap sheet.	1.7	3.9%	4.4%	17.2%	21.3%
Examples	(1) Asphalt		3.0%	2.5%	14.2%	17.6%
	(2) Coal Tar		-	0.2%	1.1%	1.9%
	(3) Coal Process		0.9%	1.7%	1.9%	1.8%
Modified Bitumen	(1) A bitumen modified through the inclusion of one or more polymers (e.g., atactic polypropylene and/or styrene butadiene styrene). (2) Composite sheets consisting of a polymer modified bitumen often reinforced and sometimes surfaced with various types of mats, films, foils, and mineral granules. It can be classified into two categories: thermoset, and thermoplastic. A thermoset material solidifies or sets irreversibly when heated; this property is usually associated with cross-linking of the molecules induced by heat or radiation. A thermoplastic material softens when heated and hardens when cooled; this process can be repeated provided that the material is not heated above the point at which decomposition occurs.	1.7	3.4%	4.9%	19.7%	23.5%
Examples	Styrene-butadiene styrene (SBS) is an elastomeric modifier containing high molecular weight polymers with both thermoset and thermoplastic properties. It is formed by the block copolymerization of styrene and butadiene monomers. These polymers are used as modifying compound in SBS polymer modified asphalt-roofing membranes to impart rubber-like qualities to the asphalt.		1.6%	3.6%	11.6%	13.7%
	Atactic polypropylene (APP) is a thermoplastic modifier containing a group of high molecular weight polymers formed by the polymerization of propylene. Used in modified bitumen as a plastic additive to permit heat fusing (torching).		1.8%	1.3%	8.1%	9.8%

			PACIFIC[b] *(steep-sloped)*		PACIFIC[b] *(low-sloped)*	
Material	Description	Median Cost[a] ($/ft²)	New Sales	Reroof Sales	New Sales	Reroof Sales
Single-ply Membrane	A roofing membrane that is field applied using just one layer of membrane material (either homogeneous or composite) rather than multiple layers. The principal roof covering is usually a single-layer flexible membrane, often of thermoset, thermoplastic, or polymer-modified bituminous compounds. Roofing membranes can be torch-applied or hot-mopped with asphalt during application.	1.5	1.3%	1.4%	43.0%	34.0%
Examples	Polyvinyl chloride (PVC) is a synthetic thermoplastic polymer prepared from vinyl chloride. PVC can be compounded into flexible and rigid forms through the use of plasticizers, stabilizers, fillers, and other modifiers. Flexible forms are used in the manufacture of sheeting and roof membrane materials.		1.3%	1.1%	5.8%	4.4%
	EPDM		-	-	27.9%	22.0%
	TPO		-	-	7.1%	5.3%
	Other Single Ply		-	0.3%	2.2%	2.3%
Metal	Metal roofs can be classified as *architectural* or *structural*.	**2.8**	**17.8%**	**11.6%**	**7.2%**	**5.0%**
Examples	Architectural (hydrokinetic-watershedding) standing-seam roof systems are typically used on steep slopes with relatively short panel lengths. They usually do not have sealant in the seam because they are designed to shed water rapidly. They do not provide structural capacity or load resistance, and their installation is less labor-intensive because they have a solid substrate platform that makes installation easier.		7.5%	6.3%	5.1%	3.5%
	Structural (hydrostatic-watershedding) standing-seam roof systems are versatile metal panel systems that can be used on both steep- and low-slope roofs and are designed to be water-resistant. Most structural standing-seam systems include a factory-applied sealant in the standing seams to help ensure water tightness. These panel systems provide structural capacity and load resistance.		10.3%	5.3%	2.1%	1.5%
Asphalt Shingle	Asphalt is a dark brown to black cementitious material, solid or semisolid, in which the predominant constituents are naturally-occurring or petroleum-derived bitumen. It is used as a weatherproofing agent. The term asphalt shingle is generically used for both fiberglass and organic shingles. There are two grades of asphalt shingles: (1) standard, a.k.a. 3-tab, and (2) architectural, a.k.a. laminated or dimensional. Asphalt shingles come in various colors	**1.3**	**43.8%**	**55.4%**	**6.6%**	**7.7%**
Examples	Fiberglass shingles, commonly known as "asphalt shingles," consist of fiber mats that are coated with asphalt and then covered with granules. Granules, a.k.a. mineral granules or ceramic granules, are opaque, naturally or synthetically colored aggregates commonly used to surface cap sheets and shingles.		43.8%	55.4%	6.2%	7.2%
	Organic shingles have a thick cellulose base that is saturated in soft asphalt. This saturation makes them heavier than fiberglass shingles, and less resistant to heat and humidity, but more durable in freezing conditions.		-	-	0.4%	0.5%

			PACIFIC[b] (steep-sloped)		PACIFIC[b] (low-sloped)	
Material	Description	Median Cost[a] ($/ft^2)	New Sales	Reroof Sales	New Sales	Reroof Sales
Fiber-cement Shingle	Fiber-cement shingles contain wood fibers that can soak up water and add an extra weight load to a house. Sometimes color is only on the surface and may need repainting after wear.	4	**0.3%**	**1.0%**	**0.4%**	**-**
Wood-shingles/ Shakes	Organic shingles have a thick cellulose base that is saturated in soft asphalt. This saturation makes them heavier than fiberglass shingles, and less resistant to heat and humidity, but more durable in freezing conditions.	1.3	**3.4%**	**3.7%**	**0.5%**	**0.7%**
Slate	Slate is a fine-grained, homogeneous, sedimentary rock composed of clay or volcanic ash which has been metamorphosed (foliated) in layers (bedded deposits). Slate can be made into roofing shingles because it has two lines of breakability: cleavage and grain.	10	**1.0%**	**1.1%**	**0.6%**	**0.5%**
Tile	Usually made of concrete or clay, tile is a combination of sand, cement, and water; the water fraction depends on the manufacturing process. Concrete tiles are either air-cured or auto-claved, whereas clay tiles are kiln-fired. Color is added to the surface of the tile with a slurry coating process, or added to the mixture during the manufacturing process.	4	20.8%	13.4%	0.9%	0.9%
Poly-urethane Foam (SPF)	A foamed plastic material, formed by spraying two components (Polymeric Methelene Diisocyanate [PMDI] and a resin) to form a rigid, fully adhered, water-resistant, and insulating membrane.	0.7	-	2.2%	1.3%	2.6%
Liquid Applied Coatings	These are used as a surfacing on roofs of various types, especially built-up and metal roofs. They are available in different colors, and may be divided on the basis of reflectivity into black, aluminum, white, and tinted coatings.	0.6	4.1%	0.7%	1.5%	1.6%
Other	All other roofing materials that are not covered under the categories mentioned above.	1	0.3%	0.2%	1.1%	2.2%

a. LBNL estimates of the typical costs are approximate from previous work - Inclusion of Cool Roofs in Nonresidential Title 24 Prescriptive Requirements (Revised August 2002, PG&E).

b. The NRCA's Pacific-region figures are derived from responses from 57 contractors compared to a total of 430 responses from over 4000 contractors to whom the survey was sent in the nation. Since the Roof Contactors Association of California reports that there are approximately 5000 active roofing contractors statewide in 2002, the NRCA figures may lack statistical validity (Hoffner, 2002).

Table 3. Leading roofing product manufacturers (Freedonia Group 1997; Builder 1995).

Company	Market Share	Leader In	Product Mix	Sales
Owens Corning	8%	asphalt-based roofing	multi-product building materials	local dealer/distributor and factory-direct
GAF Materials Corporation	7%	asphalt-based roofing	multi-product building materials	no information
France-based Saint-Gobain (via CertainTeed)	6%	asphalt-based roofing	multi-product building materials	local dealer/distributor
Jim Walter (via Celotex)	3-4%	asphalt-based roofing, coatings	multi-product building materials	local dealer/distributor
GS Roofing Products	3-4%	asphalt-based roofing	specialty	local dealer/distributor
Johns Manville	3-4%	asphalt-based roofing	multi-product building materials	local dealer/distributor and factory-direct
Carlisle Companies (via Carlisle SynTec)	3-4%	elastomeric roofing	multi-line rubber products; metal roofing	no information
Japan-based Bridgestone (via Firestone Building Products)	3-4%	elastomeric roofing	multi-line rubber products; building materials	no information
Tamko Roofing Products	<3%	asphalt-based roofing	specialty	local dealer/distributor
United Dominion Industries (via AEP Span and Varco-Pruden Buildings)	<3%	metal roofing	specialty pre-engineered buildings	no information
Gulf States Manufacturers	<3%	metal roofing	specialty pre-engineered buildings	no information
NCI Building Systems	<3%	metal roofing	specialty pre-engineered buildings	no information
Australia-based Boral (via US Tile and Lifetile)	<3%	tile	no information	local dealer/distributor
Clarke Group of Canada	<3%	cedar shingles and shakes; fiber cement roofing	no information	no information
Elcor (via Elk)	<3%	asphalt shingles	no information	local dealer/distributor
GenCorp	<3%	thermoplastic and rubber membrane roofing	no information	no information
Hood Companies	<3%	asphalt shingles and roll roofing	no information	no information
Redland of the UK (via Monier Roof Tile)	<3%	tile	no information	local dealer/distributor
Tremco	<3%	built-up and membrane roofing	no information	no information

Table 4. Cost premiums for cooler varieties of common roofing products.

Roofing Product	Cooler Variety	Cost Premium ($/ft^2)
ballasted BUR	use white gravel	up to 0.05
BUR with smooth asphalt coating	use cementitious or other white coatings	0.10 to 0.20
BUR with aluminum coating	use cementitious or other white coatings	0.10 to 0.20
single-ply membrane (EPDM, TPO, CSPE, PVC)	choose a white color	0.00 to 0.05
modified bitumen (SBS, APP)	use a white coating over the mineral surface	up to 0.05
metal roofing (both painted and unpainted)	use a white or cool color paint	0.00 to 0.05
roof coatings (dark color, asphalt base)	use a white or cool color coating	0.00 to 0.10
clay tile	use unglazed red tile, or apply a white or cool color glaze	0.00 to 0.05
concrete tile	use a white or cool color	0.05

Table 5. Life expectancies of roof materials (NRCA 1998; Lufkin and Pepitone 1997).

Roofing material	Life expectancy (yr)
wood shingles and shakes	15 to 30
tile[a]	50
slate[b]	50 to 100
sheet metal[c]	20 to 50+
BUR/asphalt[d]	12 to 25
BUR/coat and tar[d]	12 to 30
single-ply modified bitumen	10 to 20
single-ply thermoplastic	10 to 20
single-ply thermoset	10 to 20
asphalt shingle	15 to 30
asphalt overlay	25 to 35

a. Depends on quality of tile, thoroughness of design, and climate

b. Depends on grade.

c. Depends on gauge of metal, quality of coating, thoroughness of design and application.

d. Depends on materials and drainage; coatings will add to life span.

Tables 6a-f. Distribution of roof area for residences; plus simulated new roof annual energy, peak power, cooling equipment cost, and net present value (NPV) savings, with time dependent valuation (TDV). Savings are weighted by the fraction of total roof area in each California climate zone and, for steep-sloped roofs, by the fraction of new roof area for each material (56% shingle, 9% tile, and 11% metal). For each climate zone, savings and deficits for each material are included only if the material is cost effective based on a comparison of total TDV NPV savings with a cost premium of $0.20/ft^2$.

(a) Area- and Material-Weighted Savings for New Steep-Sloped Roofs [Standard Insulation, No Radiant Barrier]

		Annual TDV Energy/Mft²			Peak Power/Mft²		TDV NPV/Mft²	
Zone	Roof Area Fraction	Cooling MWh	Heating ktherm	Total MBtu	kW	k$equip	k$energy	k$total
1	0.022	0.0	0.000	0.0	0.00	0.0	0.0	0.0
2	0.034	12.6	-0.199	23.2	2.78	0.9	5.5	6.4
3	0.083	0.0	0.000	0.0	0.00	0.0	0.0	0.0
4	0.138	6.0	-0.117	8.8	2.90	0.9	2.1	3.0
5	0.107	0.0	0.000	0.0	0.00	0.0	0.0	0.0
6	0.043	0.0	0.000	0.0	0.00	0.0	0.0	0.0
7	0.016	0.6	-0.007	1.3	0.37	0.1	0.3	0.4
8	0.177	61.4	-0.410	168.4	19.78	6.0	40.2	46.3
9	0.066	25.7	-0.128	75.0	5.86	1.8	17.9	19.7
10	0.094	60.5	-0.280	178.5	11.48	3.5	42.6	46.1
11	0.062	37.7	-0.150	113.7	8.03	2.5	27.2	29.6
12	0.037	16.3	-0.106	45.1	3.11	1.0	10.8	11.7
13	0.093	69.6	-0.244	212.9	13.01	4.0	50.9	54.8
14	0.006	4.0	-0.029	10.8	0.71	0.2	2.6	2.8
15	0.008	6.7	-0.007	22.2	0.65	0.2	5.3	5.5
16	0.013	4.6	-0.050	10.6	1.97	0.6	2.5	3.1
Total	1.000	306	-1.73	870	71	22	208	229

(b) Area- and Material-Weighted Savings for New Steep-Sloped Roofs [Improved Insulation, No Radiant Barrier]

		Annual TDV Energy/Mft²			Peak Power/Mft²		TDV NPV/Mft²	
Zone	Roof Area Fraction	Cooling MWh	Heating ktherm	Total MBtu	kW	k$equip	k$energy	k$total
1	0.022	0.0	0.000	0.0	0.00	0.0	0.0	0.0
2	0.034	12.0	-0.177	23.1	2.67	0.8	5.5	6.3
3	0.083	0.0	0.000	0.0	0.00	0.0	0.0	0.0
4	0.138	0.0	0.000	0.0	0.00	0.0	0.0	0.0
5	0.107	0.0	0.000	0.0	0.00	0.0	0.0	0.0
6	0.043	0.0	0.000	0.0	0.00	0.0	0.0	0.0
7	0.016	0.6	-0.007	1.2	0.36	0.1	0.3	0.4
8	0.177	58.1	-0.365	161.9	19.37	5.9	38.7	44.6
9	0.066	24.5	-0.112	72.3	5.74	1.8	17.3	19.0
10	0.094	57.6	-0.248	171.7	11.22	3.4	41.0	44.4
11	0.062	36.0	-0.127	110.2	7.83	2.4	26.3	28.7
12	0.037	15.4	-0.089	43.7	2.97	0.9	10.4	11.3
13	0.093	66.7	-0.208	206.9	12.61	3.9	49.4	53.3
14	0.006	3.8	-0.025	10.5	0.69	0.2	2.5	2.7
15	0.008	6.4	-0.006	21.4	0.63	0.2	5.1	5.3
16	0.013	4.3	-0.042	10.4	1.92	0.6	2.5	3.1
Total	1.000	285	-1.40	833	66	20	199	219

(c) Area--Weighted Savings for New Low-Sloped Roofs [No Attic Ventilation, No Radiant Barrier]

		Annual TDV Energy/Mft²			Peak Power/Mft²		TDV NPV/Mft²	
Zone	Roof Area Fraction	Cooling MWh	Heating ktherm	Total MBtu	kW	k$equip	k$energy	k$total
1	0.022	0.0	0.000	0.0	0.00	0.0	0.0	0.0
2	0.034	0.0	0.000	0.0	0.00	0.0	0.0	0.0
3	0.083	0.0	0.000	0.0	0.00	0.0	0.0	0.0
4	0.138	0.0	0.000	0.0	0.00	0.0	0.0	0.0
5	0.107	0.0	0.000	0.0	0.00	0.0	0.0	0.0
6	0.043	0.0	0.000	0.0	0.00	0.0	0.0	0.0
7	0.016	0.0	0.000	0.0	0.00	0.0	0.0	0.0
8	0.177	82.7	-1.092	172.9	19.14	5.8	41.3	47.1
9	0.066	39.9	-0.370	99.0	7.50	2.3	23.7	25.9
10	0.094	79.1	-0.684	201.5	11.79	3.6	48.1	51.7
11	0.062	46.8	-0.394	120.5	6.30	1.9	28.8	30.7
12	0.037	23.7	-0.263	54.7	3.67	1.1	13.1	14.2
13	0.093	75.8	-0.582	200.4	10.82	3.3	47.9	51.2
14	0.006	5.0	-0.063	10.8	0.65	0.2	2.6	2.8
15	0.008	7.2	-0.018	22.9	0.83	0.3	5.5	5.7
16	0.013	6.6	-0.128	9.6	1.49	0.5	2.3	2.7
Total	1.000	367	-3.59	892	62	19	213	232

(d) Area- and Material-Weighted Savings for New Steep-Sloped Roofs [Standard Insulation, Radiant Barrier]

		Annual TDV Energy/Mft²			Peak Power/Mft²		TDV NPV/Mft²	
Zone	Roof Area Fraction	Cooling MWh	Heating ktherm	Total MBtu	kW	k$equip	k$energy	k$total
1	0.022	0.0	0.000	0.0	0.00	0.0	0.0	0.0
2	0.034	2.9	-0.045	5.4	0.84	0.3	1.3	1.5
3	0.083	0.0	0.000	0.0	0.00	0.0	0.0	0.0
4	0.138	0.0	0.000	0.0	0.00	0.0	0.0	0.0
5	0.107	0.0	0.000	0.0	0.00	0.0	0.0	0.0
6	0.043	0.0	0.000	0.0	0.00	0.0	0.0	0.0
7	0.016	0.0	0.000	0.0	0.00	0.0	0.0	0.0
8	0.177	14.5	-0.111	38.6	5.54	1.7	9.2	10.9
9	0.066	16.4	-0.087	47.4	4.40	1.3	11.3	12.7
10	0.094	36.4	-0.167	107.4	8.16	2.5	25.6	28.1
11	0.062	24.8	-0.108	73.9	4.65	1.4	17.6	19.1
12	0.037	10.7	-0.074	29.1	2.33	0.7	7.0	7.7
13	0.093	43.1	-0.168	130.3	8.29	2.5	31.1	33.6
14	0.006	2.5	-0.018	6.7	0.46	0.1	1.6	1.7
15	0.008	4.4	-0.004	14.7	0.50	0.2	3.5	3.7
16	0.013	1.1	-0.015	2.2	0.51	0.2	0.5	0.7
Total	1.000	157	-0.80	456	36	11	109	120

(e) Area- and Material-Weighted Savings for New Steep-Sloped Roofs[Improved Insulation, Radiant Barrier]

		Annual TDV Energy/Mft²			Peak Power/Mft²		TDV NPV/Mft²	
Zone	Roof Area Fraction	Cooling MWh	Heating ktherm	Total MBtu	kW	k$equip	k$energy	k$total
1	0.022	0.0	0.000	0.0	0.00	0.0	0.0	0.0
2	0.034	2.7	-0.040	5.4	0.82	0.3	1.3	1.5
3	0.083	0.0	0.000	0.0	0.00	0.0	0.0	0.0
4	0.138	0.0	0.000	0.0	0.00	0.0	0.0	0.0
5	0.107	0.0	0.000	0.0	0.00	0.0	0.0	0.0
6	0.043	0.0	0.000	0.0	0.00	0.0	0.0	0.0
7	0.016	0.0	0.000	0.0	0.00	0.0	0.0	0.0
8	0.177	14.0	-0.097	37.9	5.46	1.7	9.0	10.7
9	0.066	15.7	-0.075	45.9	4.25	1.3	11.0	12.3
10	0.094	34.7	-0.145	103.8	8.01	2.4	24.8	27.2
11	0.062	23.7	-0.091	71.8	4.48	1.4	17.2	18.5
12	0.037	10.0	-0.061	28.2	2.27	0.7	6.7	7.4
13	0.093	41.3	-0.143	126.8	8.10	2.5	30.3	32.8
14	0.006	2.4	-0.015	6.6	0.45	0.1	1.6	1.7
15	0.008	4.3	-0.004	14.3	0.49	0.1	3.4	3.6
16	0.013	1.0	-0.012	2.3	0.49	0.1	0.5	0.7
Total	1.000	150	-0.68	443	35	11	106	116

(f) Area--Weighted Savings for New Low-Sloped Roofs [No Attic Ventilation, Radiant Barrier]

		Annual TDV Energy/Mft²			Peak Power/Mft²		TDV NPV/Mft²	
Zone	Roof Area Fraction	Cooling MWh	Heating ktherm	Total MBtu	kW	k$equip	k$energy	k$total
1	0.022	0.0	0.000	0.0	0.00	0.0	0.0	0.0
2	0.034	0.0	0.000	0.0	0.00	0.0	0.0	0.0
3	0.083	0.0	0.000	0.0	0.00	0.0	0.0	0.0
4	0.138	0.0	0.000	0.0	0.00	0.0	0.0	0.0
5	0.107	0.0	0.000	0.0	0.00	0.0	0.0	0.0
6	0.043	0.0	0.000	0.0	0.00	0.0	0.0	0.0
7	0.016	0.0	0.000	0.0	0.00	0.0	0.0	0.0
8	0.177	0.0	0.000	0.0	0.00	0.0	0.0	0.0
9	0.066	0.0	0.000	0.0	0.00	0.0	0.0	0.0
10	0.094	43.7	-0.646	84.7	6.55	2.0	20.2	22.2
11	0.062	27.2	-0.372	55.7	3.09	0.9	13.3	14.2
12	0.037	0.0	0.000	0.0	0.00	0.0	0.0	0.0
13	0.093	45.7	-0.543	101.8	6.38	2.0	24.3	26.3
14	0.006	0.0	0.000	0.0	0.00	0.0	0.0	0.0
15	0.008	4.4	-0.019	13.1	0.42	0.1	3.1	3.3
16	0.013	0.0	0.000	0.0	0.00	0.0	0.0	0.0
Total	1.000	121	-1.58	255	16	5	61	66

Tables 7a-f. Distribution of roof area for residences; plus simulated reroofing annual energy, peak power, cooling equipment cost, and net present value (NPV) savings, with time dependent valuation (TDV). Savings are weighted by the fraction of total roof area in each California climate zone and, for steep-sloped roofs, by the fraction of reroofed roof area for each material (56% shingle, 9% tile, and 11% metal). For each climate zone, savings and deficits for each material are included only if the material is cost effective based on a comparison of total TDV NPV savings with a cost premium of $0.20/ft^2$.

(a) Area- and Material-Weighted Savings for Reroofed Steep-Sloped Roofs [Standard Insulation, No Radiant Barrier]

		Annual TDV Energy/Mft²			Peak Power/Mft²		TDV NPV/Mft²	
Zone	Roof Area Fraction	Cooling MWh	Heating ktherm	Total MBtu	kW	k$equip	k$energy	k$total
1	0.022	0.0	0.000	0.0	0.00	0.0	0.0	0.0
2	0.034	12.6	-0.199	23.2	2.78	0.9	5.5	6.4
3	0.083	0.0	0.000	0.0	0.00	0.0	0.0	0.0
4	0.138	6.0	-0.117	8.8	2.90	0.9	2.1	3.0
5	0.107	0.0	0.000	0.0	0.00	0.0	0.0	0.0
6	0.043	0.0	0.000	0.0	0.00	0.0	0.0	0.0
7	0.016	0.6	-0.007	1.3	0.37	0.1	0.3	0.4
8	0.177	61.4	-0.410	168.4	19.78	6.0	40.2	46.3
9	0.066	25.7	-0.128	75.0	5.86	1.8	17.9	19.7
10	0.094	60.5	-0.280	178.5	11.48	3.5	42.6	46.1
11	0.062	37.7	-0.150	113.7	8.03	2.5	27.2	29.6
12	0.037	16.3	-0.106	45.1	3.11	1.0	10.8	11.7
13	0.093	69.6	-0.244	212.9	13.01	4.0	50.9	54.8
14	0.006	4.0	-0.029	10.8	0.71	0.2	2.6	2.8
15	0.008	6.7	-0.007	22.2	0.65	0.2	5.3	5.5
16	0.013	4.6	-0.050	10.6	1.97	0.6	2.5	3.1
Total	1.000	306	-1.73	870	71	22	208	229

(b) Area- and Material-Weighted Savings for Reroofed Steep-Sloped Roofs [Improved Insulation, No Radiant Barrier]

		Annual TDV Energy/Mft²			Peak Power/Mft²		TDV NPV/Mft²	
Zone	Roof Area Fraction	Cooling MWh	Heating ktherm	Total MBtu	kW	k$equip	k$energy	k$total
1	0.022	0.0	0.000	0.0	0.00	0.0	0.0	0.0
2	0.034	12.0	-0.177	23.1	2.67	0.8	5.5	6.3
3	0.083	0.0	0.000	0.0	0.00	0.0	0.0	0.0
4	0.138	0.0	0.000	0.0	0.00	0.0	0.0	0.0
5	0.107	0.0	0.000	0.0	0.00	0.0	0.0	0.0
6	0.043	0.0	0.000	0.0	0.00	0.0	0.0	0.0
7	0.016	0.6	-0.007	1.2	0.36	0.1	0.3	0.4
8	0.177	58.1	-0.365	161.9	19.37	5.9	38.7	44.6
9	0.066	24.5	-0.112	72.3	5.74	1.8	17.3	19.0
10	0.094	57.6	-0.248	171.7	11.22	3.4	41.0	44.4
11	0.062	36.0	-0.127	110.2	7.83	2.4	26.3	28.7
12	0.037	15.4	-0.089	43.7	2.97	0.9	10.4	11.3
13	0.093	66.7	-0.208	206.9	12.61	3.9	49.4	53.3
14	0.006	3.8	-0.025	10.5	0.69	0.2	2.5	2.7
15	0.008	6.4	-0.006	21.4	0.63	0.2	5.1	5.3
16	0.013	4.3	-0.042	10.4	1.92	0.6	2.5	3.1
Total	1.000	285	-1.40	833	66	20	199	219

(c) Area-Weighted Savings for Reroofed Low-Sloped Roofs [No Attic Ventilation, No Radiant Barrier]

		Annual TDV Energy/Mft²			Peak Power/Mft²		TDV NPV/Mft²	
Zone	Roof Area Fraction	Cooling MWh	Heating ktherm	Total MBtu	kW	k$equip	k$energy	k$total
1	0.022	0.0	0.000	0.0	0.00	0.0	0.0	0.0
2	0.034	0.0	0.000	0.0	0.00	0.0	0.0	0.0
3	0.083	0.0	0.000	0.0	0.00	0.0	0.0	0.0
4	0.138	0.0	0.000	0.0	0.00	0.0	0.0	0.0
5	0.107	0.0	0.000	0.0	0.00	0.0	0.0	0.0
6	0.043	0.0	0.000	0.0	0.00	0.0	0.0	0.0
7	0.016	0.0	0.000	0.0	0.00	0.0	0.0	0.0
8	0.177	82.7	-1.092	172.9	19.14	5.8	41.3	47.1
9	0.066	39.9	-0.370	99.0	7.50	2.3	23.7	25.9
10	0.094	79.1	-0.684	201.5	11.79	3.6	48.1	51.7
11	0.062	46.8	-0.394	120.5	6.30	1.9	28.8	30.7
12	0.037	23.7	-0.263	54.7	3.67	1.1	13.1	14.2
13	0.093	75.8	-0.582	200.4	10.82	3.3	47.9	51.2
14	0.006	5.0	-0.063	10.8	0.65	0.2	2.6	2.8
15	0.008	7.2	-0.018	22.9	0.83	0.3	5.5	5.7
16	0.013	6.6	-0.128	9.6	1.49	0.5	2.3	2.7
Total	1.000	367	-3.59	892	62	19	213	232

(d) Area- and Material-Weighted Savings for Reroofed Steep-Sloped Roofs [Standard Insulation, Radiant Barrier]

		Annual TDV Energy/Mft²			Peak Power/Mft²		TDV NPV/Mft²	
Zone	Roof Area Fraction	Cooling MWh	Heating ktherm	Total MBtu	kW	k$equip	k$energy	k$total
1	0.022	0.0	0.000	0.0	0.00	0.0	0.0	0.0
2	0.034	2.9	-0.045	5.4	0.84	0.3	1.3	1.5
3	0.083	0.0	0.000	0.0	0.00	0.0	0.0	0.0
4	0.138	0.0	0.000	0.0	0.00	0.0	0.0	0.0
5	0.107	0.0	0.000	0.0	0.00	0.0	0.0	0.0
6	0.043	0.0	0.000	0.0	0.00	0.0	0.0	0.0
7	0.016	0.0	0.000	0.0	0.00	0.0	0.0	0.0
8	0.177	14.5	-0.111	38.6	5.54	1.7	9.2	10.9
9	0.066	16.4	-0.087	47.4	4.40	1.3	11.3	12.7
10	0.094	36.4	-0.167	107.4	8.16	2.5	25.6	28.1
11	0.062	24.8	-0.108	73.9	4.65	1.4	17.6	19.1
12	0.037	10.7	-0.074	29.1	2.33	0.7	7.0	7.7
13	0.093	43.1	-0.168	130.3	8.29	2.5	31.1	33.6
14	0.006	2.5	-0.018	6.7	0.46	0.1	1.6	1.7
15	0.008	4.4	-0.004	14.7	0.50	0.2	3.5	3.7
16	0.013	1.1	-0.015	2.2	0.51	0.2	0.5	0.7
Total	1.000	157	-0.80	456	36	11	109	120

(e) Area- and Material-Weighted Savings for Reroofed Steep-Sloped Roofs [Improved Insulation, Radiant Barrier]

		Annual TDV Energy/Mft²			Peak Power/Mft²		TDV NPV/Mft²	
Zone	Roof Area Fraction	Cooling MWh	Heating ktherm	Total MBtu	kW	k$equip	k$energy	k$total
1	0.022	0.0	0.000	0.0	0.00	0.0	0.0	0.0
2	0.034	2.7	-0.040	5.4	0.82	0.3	1.3	1.5
3	0.083	0.0	0.000	0.0	0.00	0.0	0.0	0.0
4	0.138	0.0	0.000	0.0	0.00	0.0	0.0	0.0
5	0.107	0.0	0.000	0.0	0.00	0.0	0.0	0.0
6	0.043	0.0	0.000	0.0	0.00	0.0	0.0	0.0
7	0.016	0.0	0.000	0.0	0.00	0.0	0.0	0.0
8	0.177	14.0	-0.097	37.9	5.46	1.7	9.0	10.7
9	0.066	15.7	-0.075	45.9	4.25	1.3	11.0	12.3
10	0.094	34.7	-0.145	103.8	8.01	2.4	24.8	27.2
11	0.062	23.7	-0.091	71.8	4.48	1.4	17.2	18.5
12	0.037	10.0	-0.061	28.2	2.27	0.7	6.7	7.4
13	0.093	41.3	-0.143	126.8	8.10	2.5	30.3	32.8
14	0.006	2.4	-0.015	6.6	0.45	0.1	1.6	1.7
15	0.008	4.3	-0.004	14.3	0.49	0.1	3.4	3.6
16	0.013	1.0	-0.012	2.3	0.49	0.1	0.5	0.7
Total	1.000	150	-0.68	443	35	11	106	116

(f) Area-Weighted Savings for Reroofed Low-Sloped Roofs [No Attic Ventilation, Radiant Barrier]

		Annual TDV Energy/Mft²			Peak Power/Mft²		TDV NPV/Mft²	
Zone	Roof Area Fraction	Cooling MWh	Heating ktherm	Total MBtu	kW	k$equip	k$energy	k$total
1	0.022	0.0	0.000	0.0	0.00	0.0	0.0	0.0
2	0.034	0.0	0.000	0.0	0.00	0.0	0.0	0.0
3	0.083	0.0	0.000	0.0	0.00	0.0	0.0	0.0
4	0.138	0.0	0.000	0.0	0.00	0.0	0.0	0.0
5	0.107	0.0	0.000	0.0	0.00	0.0	0.0	0.0
6	0.043	0.0	0.000	0.0	0.00	0.0	0.0	0.0
7	0.016	0.0	0.000	0.0	0.00	0.0	0.0	0.0
8	0.177	0.0	0.000	0.0	0.00	0.0	0.0	0.0
9	0.066	0.0	0.000	0.0	0.00	0.0	0.0	0.0
10	0.094	43.7	-0.646	84.7	6.55	2.0	20.2	22.2
11	0.062	27.2	-0.372	55.7	3.09	0.9	13.3	14.2
12	0.037	0.0	0.000	0.0	0.00	0.0	0.0	0.0
13	0.093	45.7	-0.543	101.8	6.38	2.0	24.3	26.3
14	0.006	0.0	0.000	0.0	0.00	0.0	0.0	0.0
15	0.008	4.4	-0.019	13.1	0.42	0.1	3.1	3.3
16	0.013	0.0	0.000	0.0	0.00	0.0	0.0	0.0
Total	1.000	121	-1.58	255	16	5	61	66

Tables 8a-c. Estimated annual state-wide new and reroofed roof area for residences with air-conditioning; plus simulated statewide annual energy, peak power, cooling equipment cost, and net present value (NPV) of time dependent valuation (TDV) savings from increased roof solar reflectance with attic radiant barriers in climate zones 2, 4, and 8 through 15 and no radiant barriers in other climate zones.

(a) State-Wide Savings for Steep-Sloped Roofs (Standard Insulation)

	Mft2 air-conditioned roof area	Annual TDV Energy			Peak Demand		TDV NPV	
		GWh	ktherm	GBTU	MW	M$equip	M$energy	M$total
New	51	11	-58	30	2.6	0.8	7.3	8.1
Reroof	197	39	-210	112	9.6	2.9	27	30
Total	248	50	-269	142	12	3.8	34	38

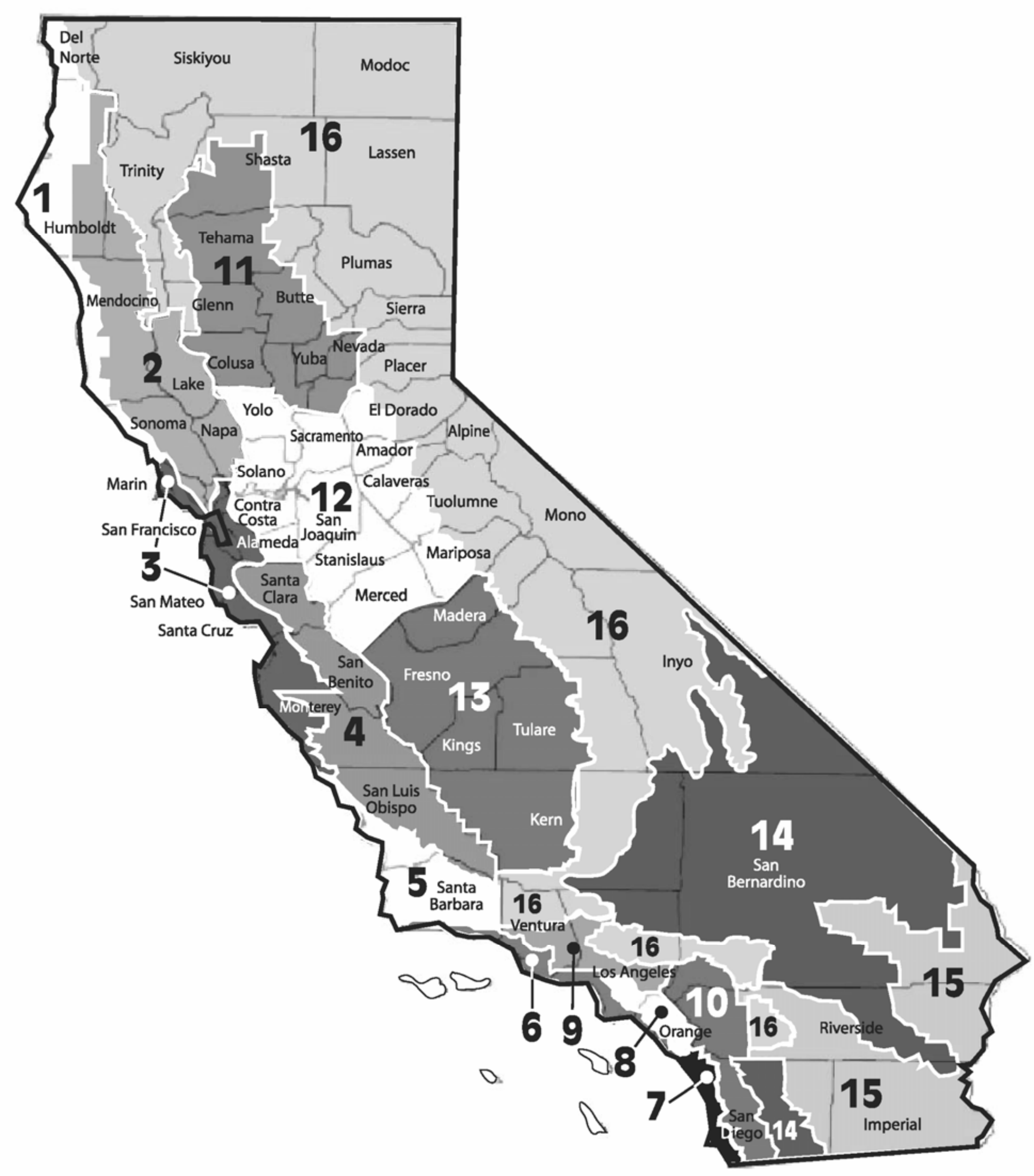
(b) State-Wide Savings for Steep-Sloped Roofs (Improved Insulation)

	Mft2 air-conditioned roof area	Annual TDV Energy			Peak Demand		TDV NPV	
		GWh	ktherm	GBTU	MW	M$equip	M$energy	M$total
New	51	10	-50	29	2.6	0.8	7.0	7.8
Reroof	197	37	-182	108	9.4	2.9	26	29
Total	248	47	-232	138	12	3.7	33	37

(c) State-Wide Savings for Low-Sloped Roofs (No Attic Ventilation)

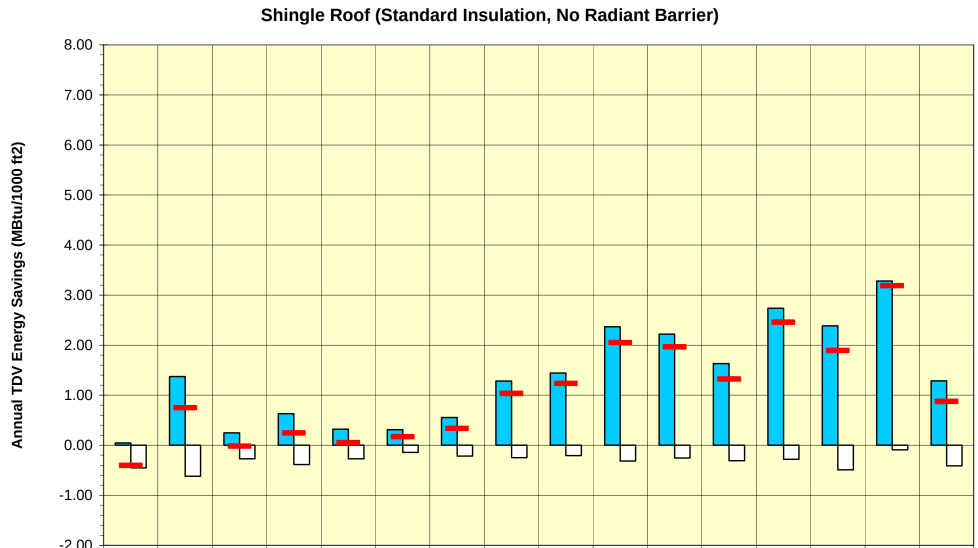
	Mft2 air-conditioned roof area	Annual TDV Energy			Peak Demand		TDV NPV	
		GWh	ktherm	GBTU	MW	M$equip	M$energy	M$total
New	13	3.2	-41	6.9	0.6	0.2	1.6	1.8
Reroof	49	12.3	-156	26	2.2	0.7	6.3	7.0
Total	62	15.5	-196	33	2.8	0.8	7.9	8.8

Figure 1. Locations of the 16 California climate zones (courtesy Eley Associates).



Figures 2a-n. Annual TDV-weighted energy savings (MBTU/1000 ft²) versus California climate zone, simulated for a prototypical Title-24 building.

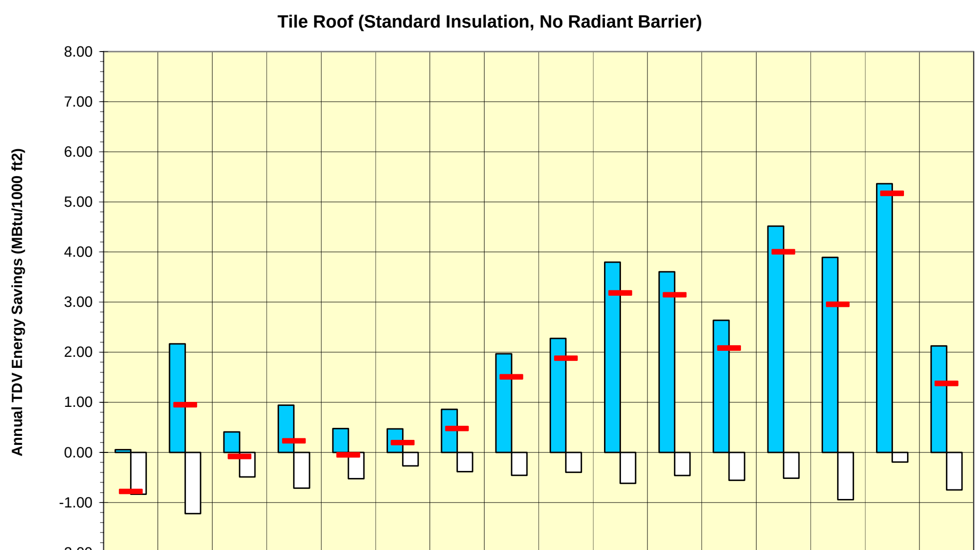
(a)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Cooling	0.05	1.37	0.25	0.63	0.32	0.31	0.55	1.28	1.44	2.37	2.22	1.63	2.74	2.39	3.28	1.29
Heating	-0.45	-0.62	-0.27	-0.39	-0.27	-0.14	-0.22	-0.25	-0.21	-0.32	-0.26	-0.31	-0.28	-0.49	-0.09	-0.41
Total	-0.41	0.75	-0.02	0.24	0.05	0.17	0.34	1.04	1.24	2.05	1.97	1.32	2.46	1.89	3.19	0.88

California Climate Zone

(b)

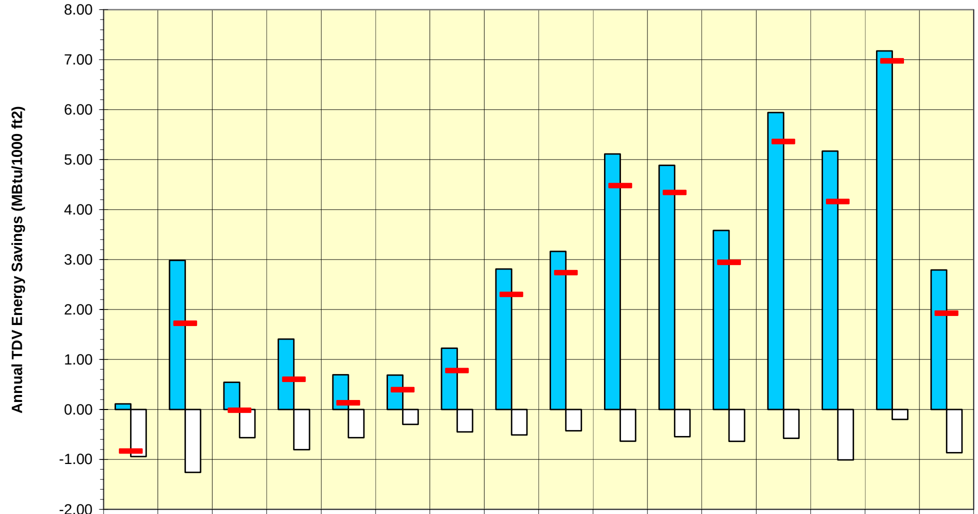


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Cooling	0.05	2.17	0.41	0.94	0.47	0.47	0.86	1.97	2.28	3.80	3.61	2.64	4.52	3.89	5.36	2.12
Heating	-0.83	-1.22	-0.49	-0.71	-0.52	-0.27	-0.38	-0.46	-0.40	-0.62	-0.46	-0.56	-0.52	-0.94	-0.19	-0.75
Total	-0.78	0.95	-0.08	0.23	-0.05	0.20	0.48	1.51	1.88	3.18	3.14	2.08	4.00	2.95	5.17	1.38

California Climate Zone

(c)

Metal Roof (Standard Insulation, No Radiant Barrier)

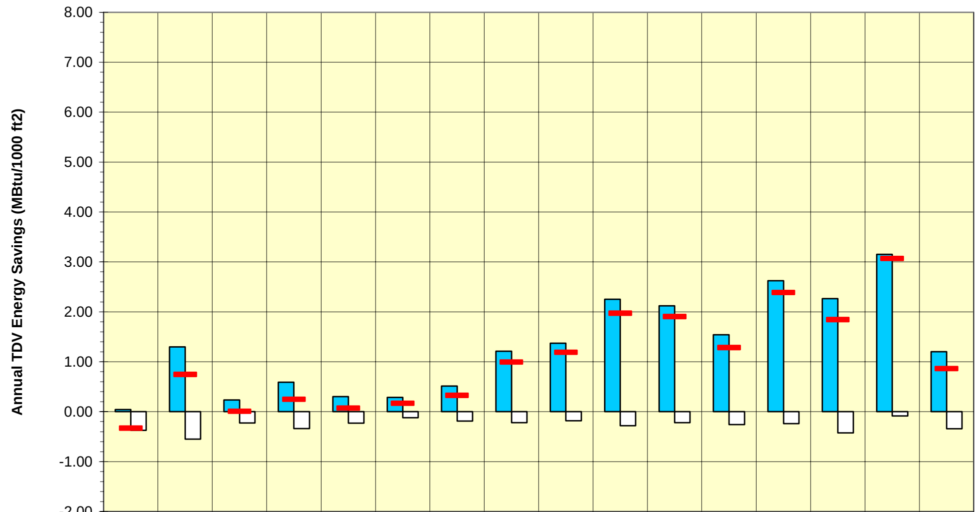


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Cooling	0.11	2.98	0.54	1.41	0.69	0.69	1.23	2.81	3.16	5.11	4.89	3.58	5.94	5.17	7.17	2.79
Heating	-0.94	-1.26	-0.56	-0.81	-0.56	-0.30	-0.45	-0.51	-0.43	-0.63	-0.55	-0.64	-0.58	-1.01	-0.20	-0.87
Total	-0.83	1.72	-0.02	0.60	0.13	0.39	0.78	2.30	2.74	4.48	4.34	2.94	5.36	4.16	6.97	1.92

California Climate Zone

(d)

Shingle Roof (Improved Insulation, No Radiant Barrier)

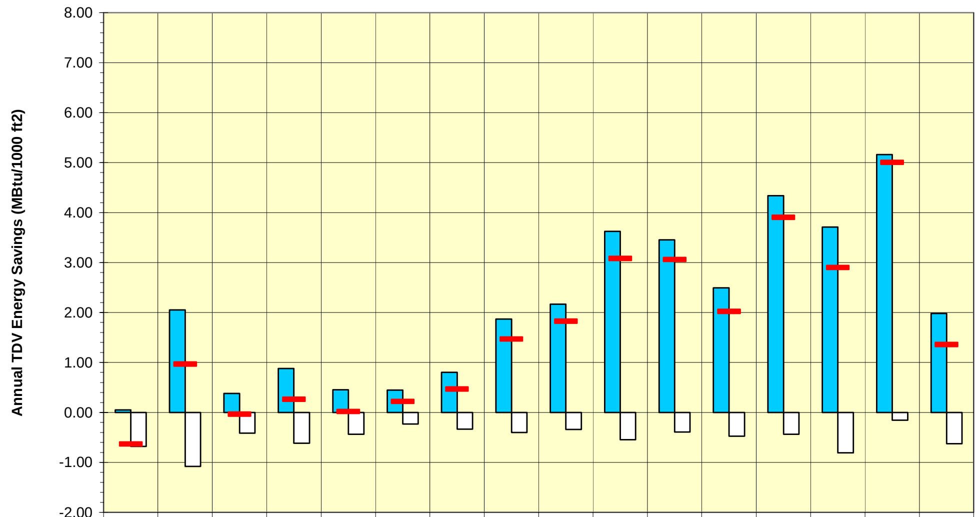


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Cooling	0.04	1.30	0.23	0.59	0.30	0.29	0.52	1.21	1.37	2.25	2.12	1.54	2.62	2.27	3.15	1.20
Heating	-0.37	-0.55	-0.23	-0.34	-0.23	-0.12	-0.19	-0.22	-0.18	-0.28	-0.22	-0.26	-0.24	-0.42	-0.08	-0.34
Total	-0.33	0.75	0.01	0.25	0.07	0.17	0.33	0.99	1.19	1.97	1.90	1.28	2.39	1.84	3.07	0.86

California Climate Zone

(e)

Tile Roof (Improved Insulation, No Radiant Barrier)

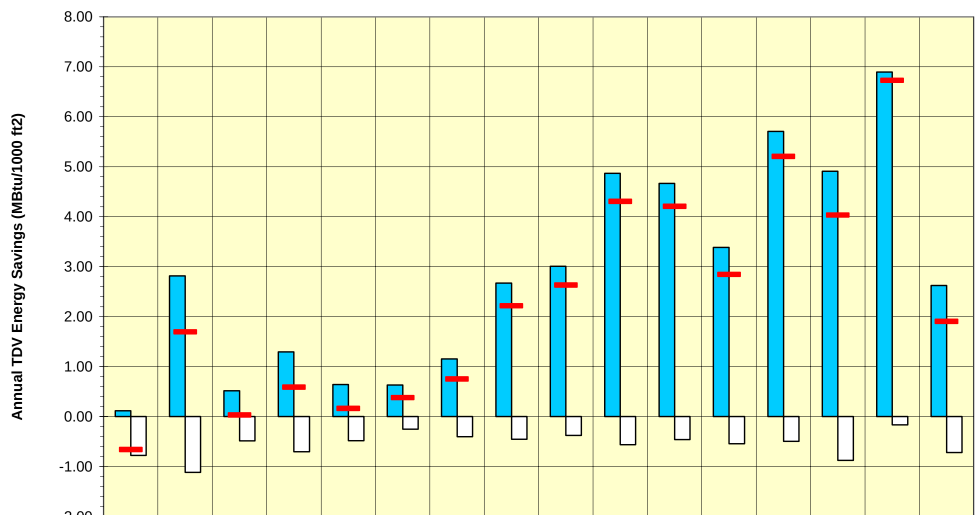


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Cooling	0.05	2.05	0.38	0.88	0.45	0.45	0.80	1.87	2.17	3.63	3.45	2.49	4.34	3.71	5.16	1.98
Heating	-0.68	-1.08	-0.42	-0.62	-0.44	-0.23	-0.33	-0.40	-0.34	-0.55	-0.39	-0.47	-0.44	-0.81	-0.16	-0.62
Total	-0.63	0.97	-0.03	0.26	0.02	0.22	0.47	1.47	1.82	3.08	3.06	2.02	3.90	2.90	5.00	1.36

California Climate Zone

(f)

Metal Roof (Improved Insulation, No Radiant Barrier)

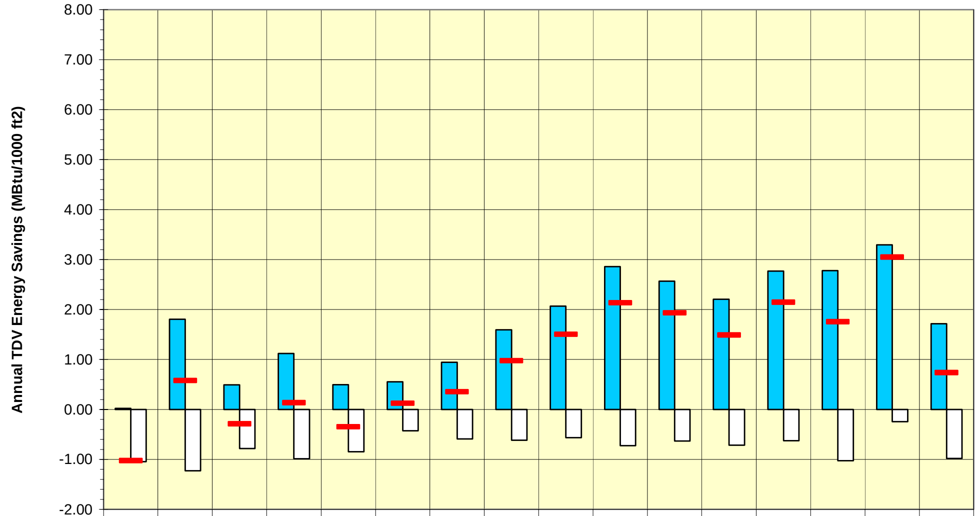


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Cooling	0.12	2.81	0.52	1.29	0.64	0.63	1.15	2.67	3.01	4.87	4.67	3.39	5.70	4.91	6.89	2.63
Heating	-0.78	-1.12	-0.48	-0.70	-0.48	-0.25	-0.40	-0.45	-0.38	-0.56	-0.46	-0.54	-0.50	-0.88	-0.17	-0.72
Total	-0.66	1.70	0.03	0.59	0.16	0.38	0.75	2.22	2.63	4.31	4.21	2.84	5.21	4.03	6.73	1.91

California Climate Zone

(g)

Flat Built-Up Roof (No Attic Ventilation, No Radiant Barrier)

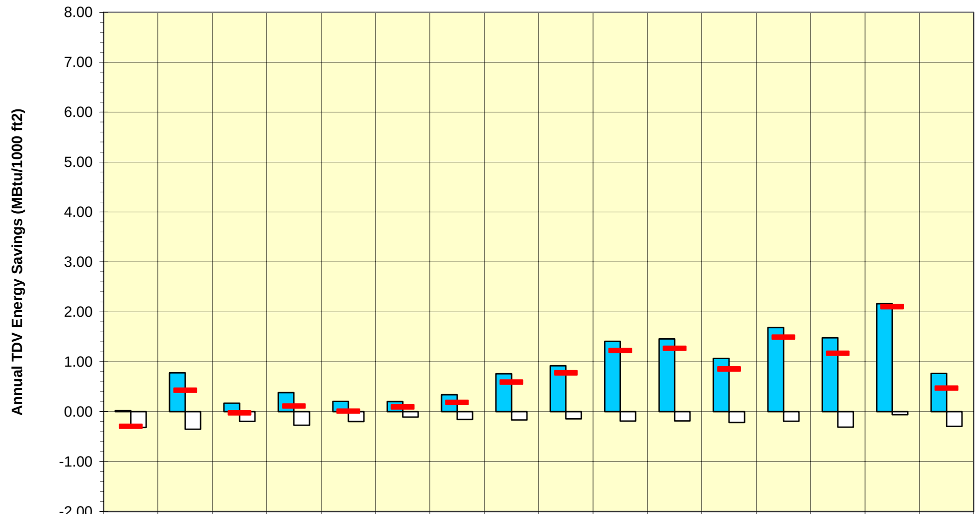


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Cooling	0.02	1.80	0.49	1.12	0.50	0.55	0.94	1.59	2.07	2.86	2.57	2.21	2.77	2.78	3.30	1.72
Heating	-1.05	-1.23	-0.78	-0.98	-0.85	-0.43	-0.59	-0.62	-0.56	-0.72	-0.63	-0.72	-0.62	-1.02	-0.25	-0.98
Total	-1.03	0.58	-0.29	0.13	-0.35	0.13	0.36	0.98	1.50	2.13	1.93	1.49	2.15	1.75	3.05	0.74

California Climate Zone

(h)

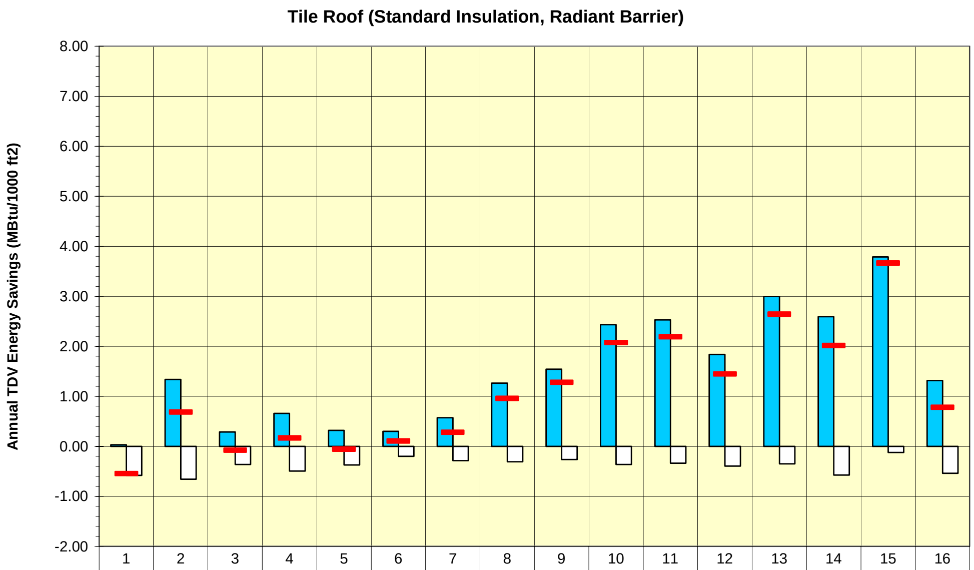
Shingle Roof (Standard Insulation, Radiant Barrier)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Cooling	0.02	0.78	0.17	0.38	0.21	0.20	0.34	0.76	0.92	1.41	1.46	1.07	1.68	1.48	2.16	0.77
Heating	-0.31	-0.35	-0.20	-0.27	-0.20	-0.11	-0.15	-0.17	-0.14	-0.19	-0.19	-0.21	-0.19	-0.31	-0.06	-0.29
Total	-0.29	0.43	-0.03	0.11	0.01	0.09	0.19	0.59	0.78	1.22	1.27	0.85	1.49	1.17	2.10	0.47

California Climate Zone

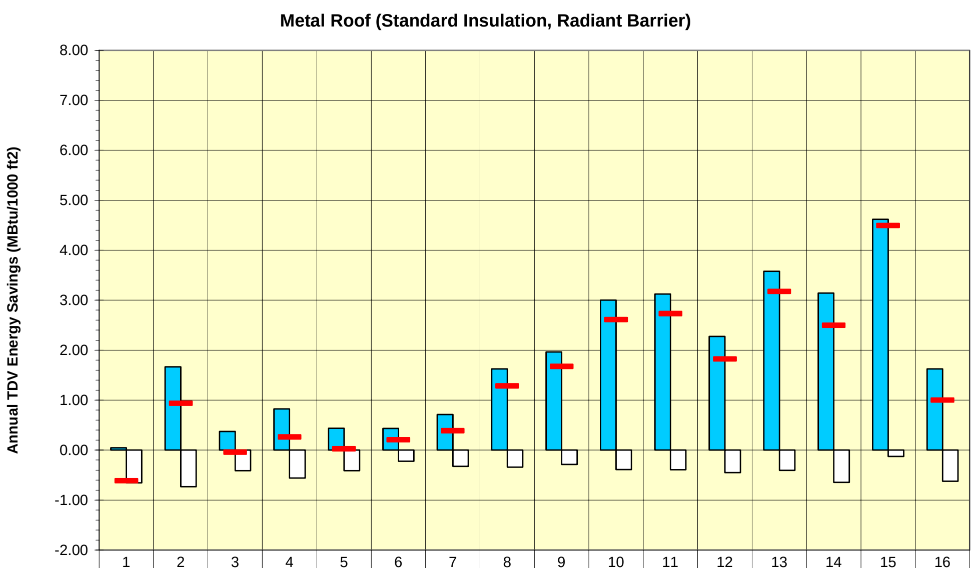
(i)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Cooling	0.03	1.34	0.29	0.66	0.32	0.30	0.57	1.26	1.54	2.43	2.53	1.84	3.00	2.59	3.79	1.32
Heating	-0.58	-0.65	-0.36	-0.49	-0.37	-0.20	-0.29	-0.31	-0.26	-0.36	-0.34	-0.39	-0.35	-0.58	-0.12	-0.54
Total	-0.55	0.68	-0.08	0.17	-0.06	0.10	0.28	0.96	1.28	2.07	2.19	1.45	2.64	2.02	3.66	0.78

California Climate Zone

(j)

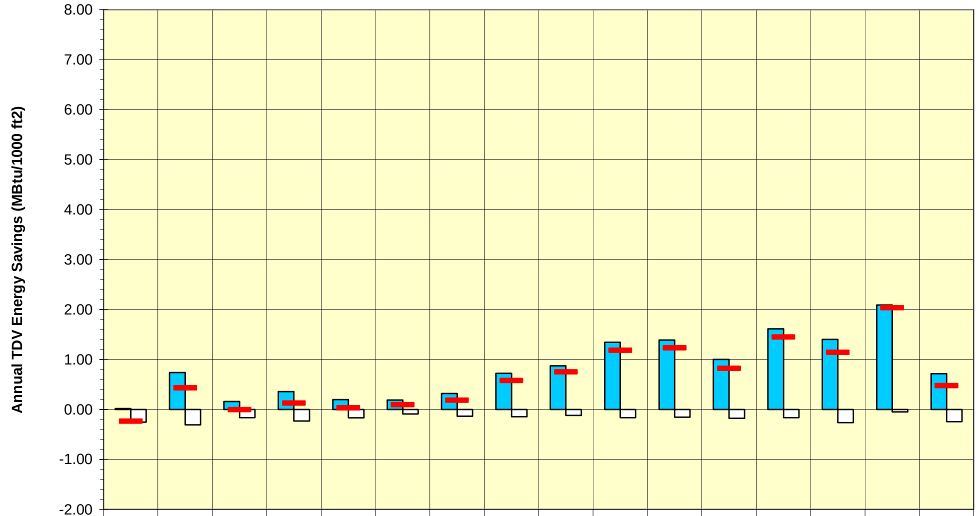


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Cooling	0.05	1.67	0.37	0.82	0.44	0.43	0.71	1.63	1.96	3.00	3.12	2.27	3.58	3.14	4.62	1.63
Heating	-0.66	-0.73	-0.41	-0.56	-0.41	-0.23	-0.32	-0.34	-0.29	-0.39	-0.39	-0.45	-0.40	-0.65	-0.13	-0.63
Total	-0.61	0.94	-0.04	0.26	0.02	0.21	0.39	1.28	1.68	2.61	2.73	1.82	3.17	2.50	4.49	1.00

California Climate Zone

(k)

Shingle Roof (Improved Insulation, Radiant Barrier)

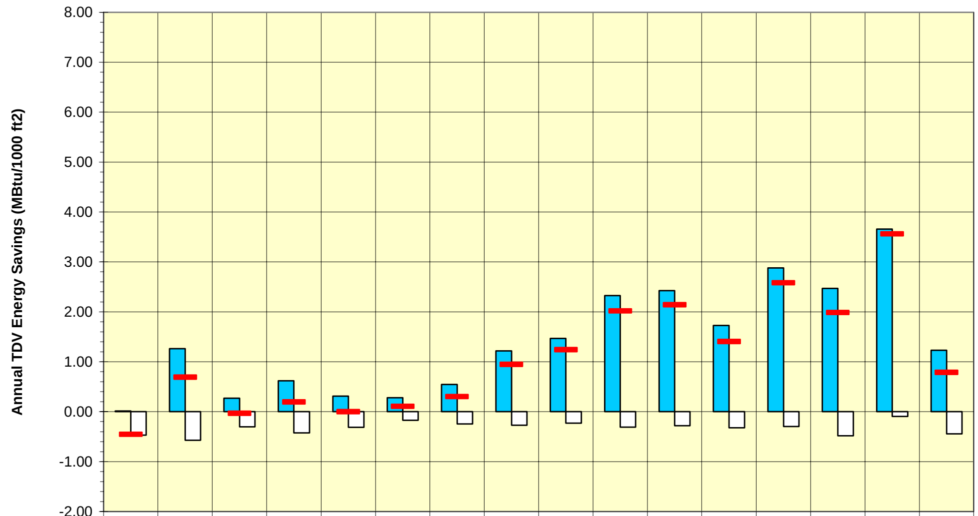


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Cooling	0.02	0.74	0.16	0.36	0.20	0.19	0.32	0.72	0.87	1.35	1.39	1.00	1.61	1.40	2.09	0.72
Heating	-0.25	-0.31	-0.16	-0.23	-0.17	-0.09	-0.14	-0.15	-0.12	-0.16	-0.16	-0.18	-0.16	-0.26	-0.05	-0.24
Total	-0.23	0.43	0.00	0.13	0.03	0.10	0.18	0.58	0.75	1.18	1.23	0.82	1.45	1.14	2.04	0.47

California Climate Zone

(l)

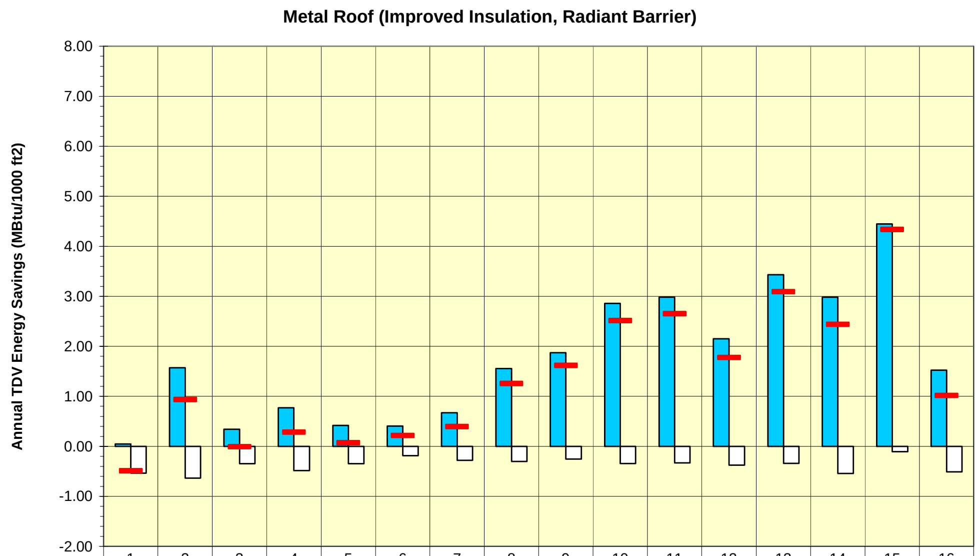
Tile Roof (Improved Insulation, Radiant Barrier)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Cooling	0.01	1.26	0.27	0.62	0.31	0.28	0.55	1.22	1.47	2.33	2.43	1.73	2.88	2.47	3.65	1.23
Heating	-0.47	-0.57	-0.30	-0.42	-0.31	-0.17	-0.24	-0.27	-0.23	-0.31	-0.28	-0.32	-0.30	-0.48	-0.10	-0.44
Total	-0.45	0.69	-0.03	0.20	0.00	0.11	0.30	0.95	1.24	2.02	2.14	1.40	2.58	1.99	3.56	0.79

California Climate Zone

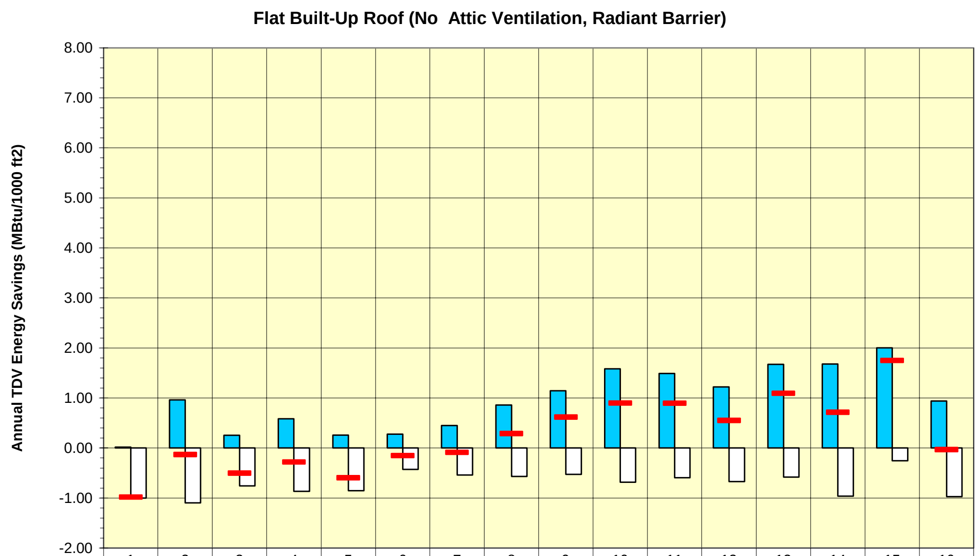
(m)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Cooling	0.05	1.57	0.34	0.77	0.42	0.40	0.67	1.56	1.87	2.86	2.98	2.15	3.43	2.98	4.45	1.53
Heating	-0.54	-0.64	-0.35	-0.48	-0.35	-0.19	-0.28	-0.30	-0.25	-0.34	-0.33	-0.38	-0.34	-0.54	-0.11	-0.51
Total	-0.49	0.94	-0.01	0.28	0.07	0.22	0.39	1.25	1.62	2.51	2.65	1.78	3.09	2.44	4.34	1.02

California Climate Zone

(n)

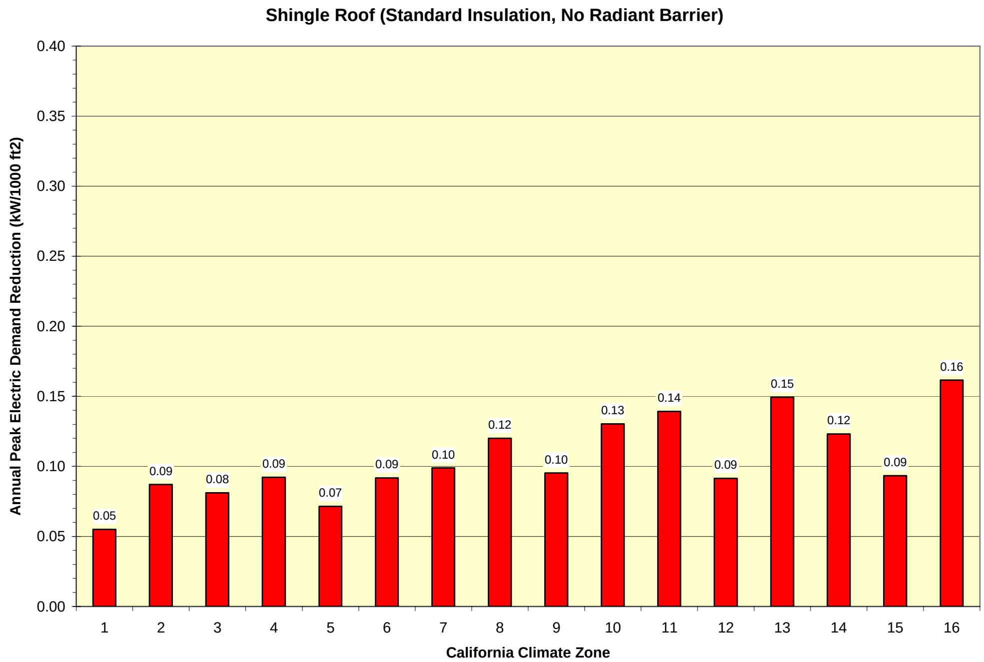


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Cooling	0.02	0.96	0.26	0.59	0.26	0.28	0.45	0.86	1.15	1.58	1.49	1.22	1.67	1.68	2.00	0.94
Heating	-1.00	-1.09	-0.76	-0.87	-0.85	-0.43	-0.54	-0.57	-0.53	-0.68	-0.60	-0.67	-0.58	-0.96	-0.25	-0.97
Total	-0.98	-0.13	-0.50	-0.28	-0.60	-0.15	-0.09	0.29	0.62	0.90	0.89	0.55	1.09	0.71	1.75	-0.03

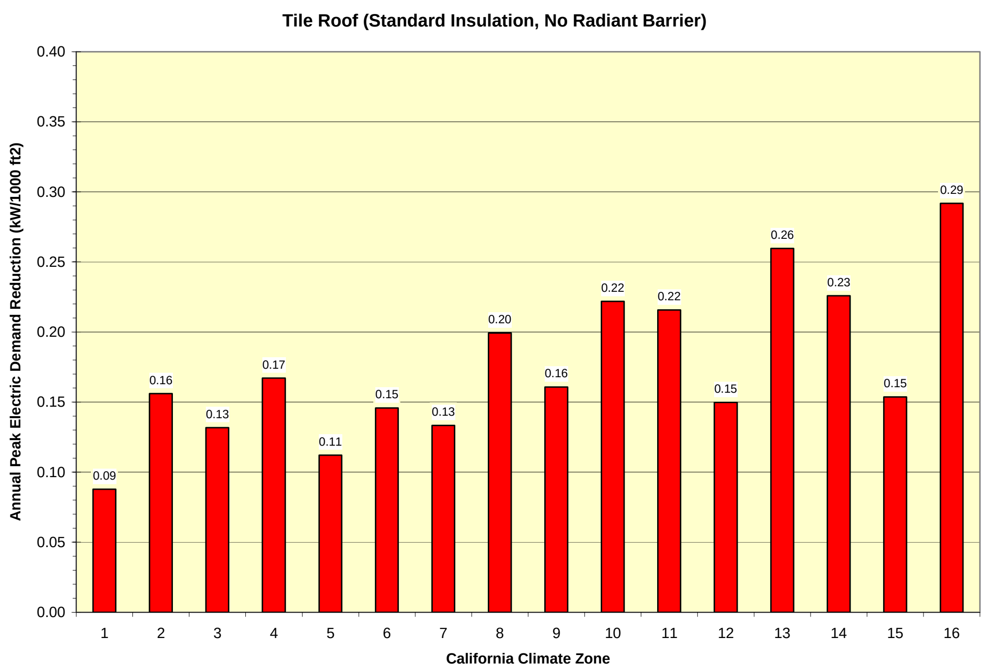
California Climate Zone

Figures 3a-n. Annual peak electric demand reduction (kW/1000 ft²) versus California climate zone, simulated for a prototypical Title-24 building.

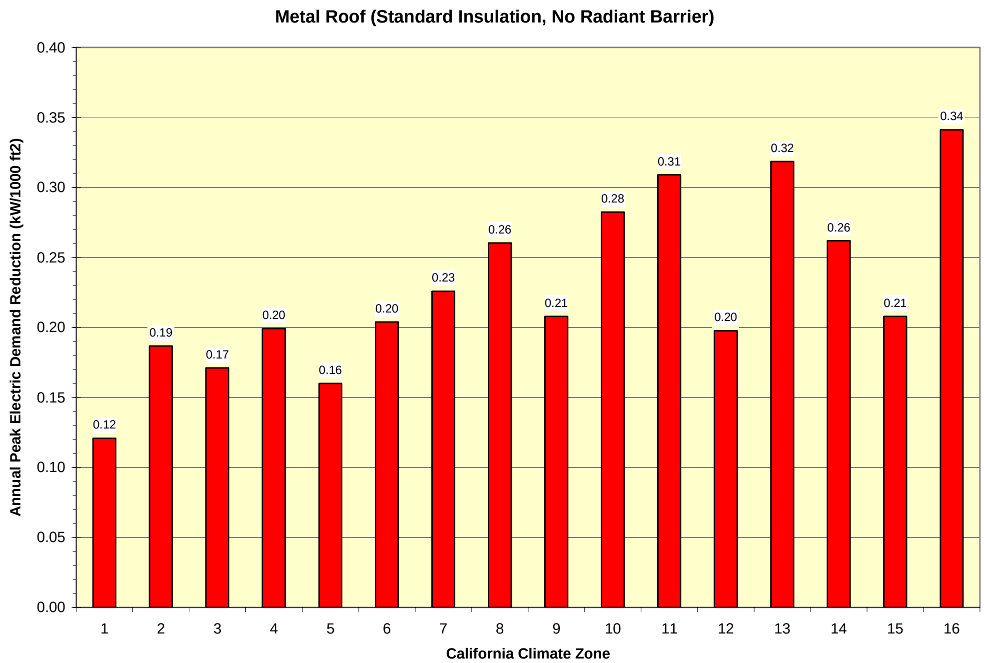
(a)



(b)



(c)


Metal Roof (Standard Insulation, No Radiant Barrier)
Annual Peak Electric Demand Reduction (kW/1000 ft2)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.12
0.19
0.17
0.20
0.16
0.20
0.23
0.26
0.21
0.28
0.31
0.20
0.32
0.26
0.21
0.34
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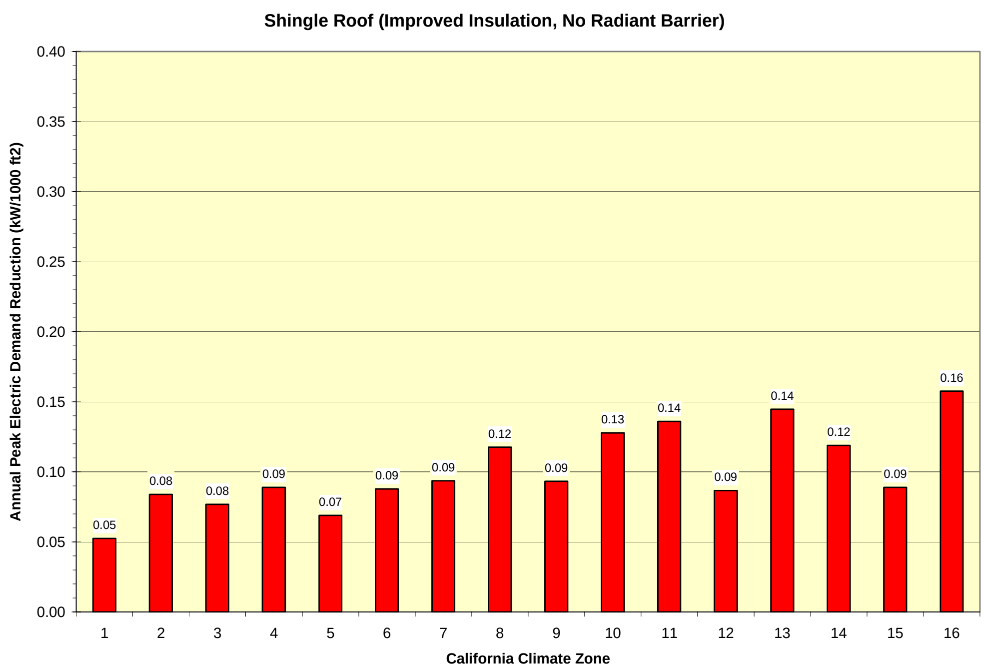
16
California Climate Zone

(d)


Shingle Roof (Improved Insulation, No Radiant Barrier)
Annual Peak Electric Demand Reduction (kW/1000 ft2)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.05
0.08
0.08
0.09
0.07
0.09
0.09
0.12
0.09
0.13
0.14
0.09
0.14
0.12
0.09
0.16
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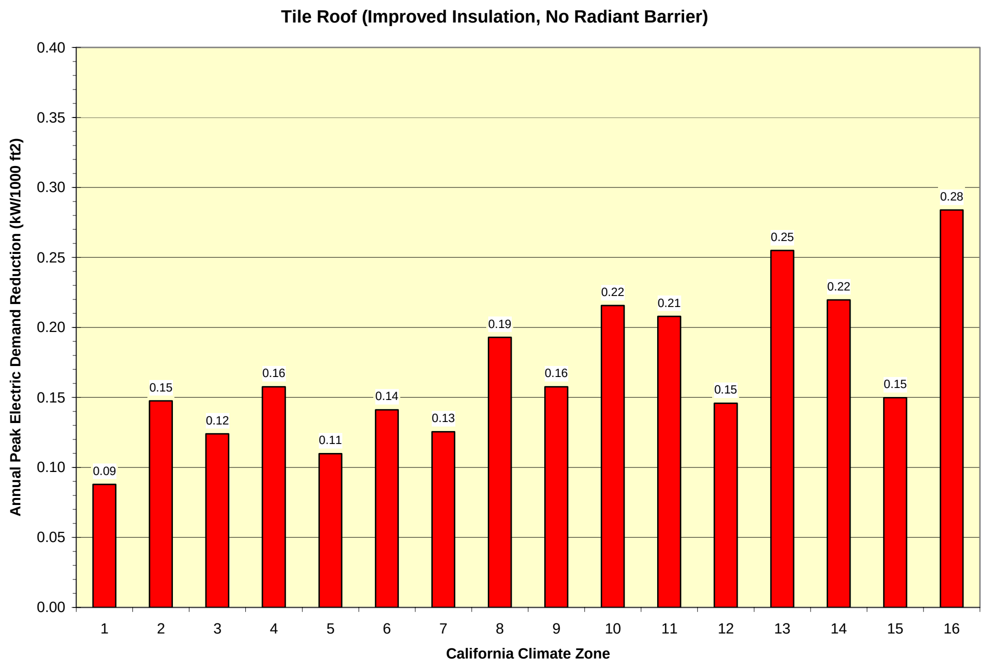
16
California Climate Zone

(e)


Tile Roof (Improved Insulation, No Radiant Barrier)
Annual Peak Electric Demand Reduction (kW/1000 ft2)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.09
0.15
0.12
0.16
0.11
0.14
0.13
0.19
0.16
0.22
0.21
0.15
0.25
0.22
0.15
0.28
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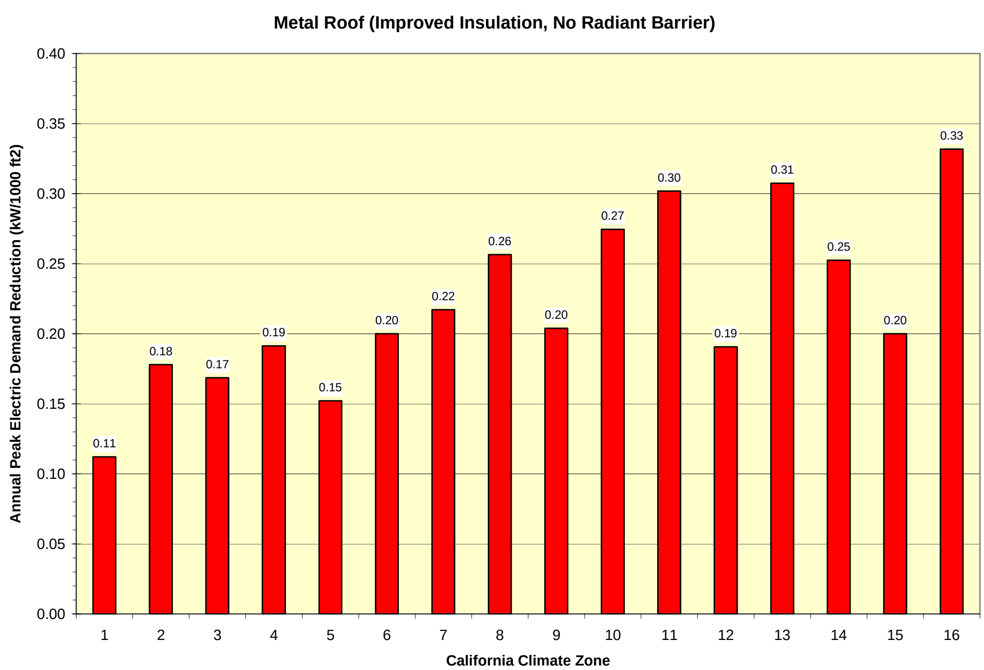
16
California Climate Zone

(f)


Metal Roof (Improved Insulation, No Radiant Barrier)
Annual Peak Electric Demand Reduction (kW/1000 ft2)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.11
0.18
0.17
0.19
0.15
0.20
0.22
0.26
0.20
0.27
0.30
0.19
0.31
0.25
0.20
0.33
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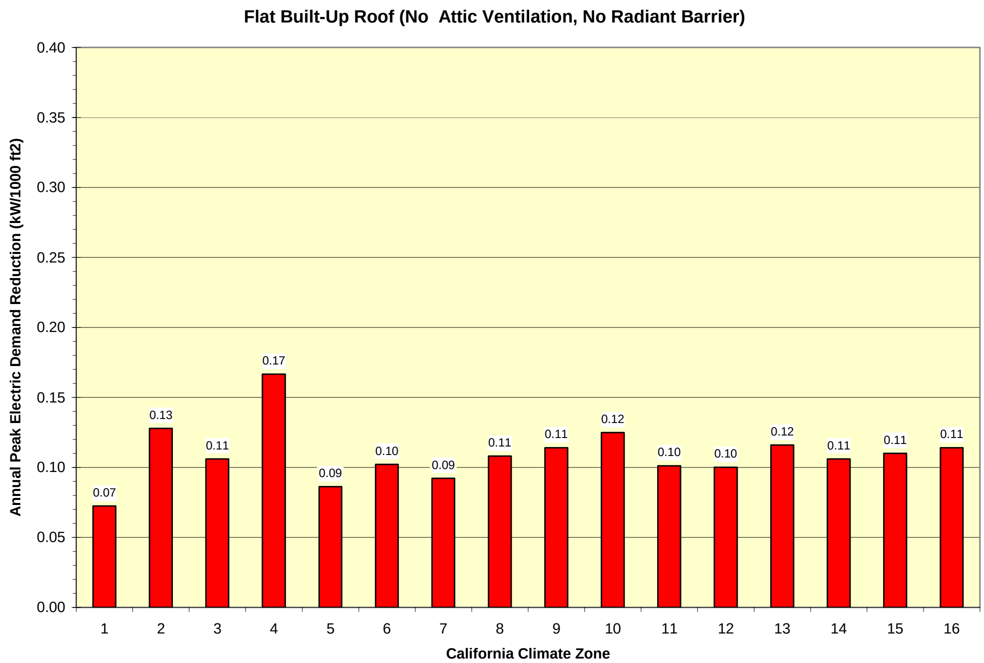
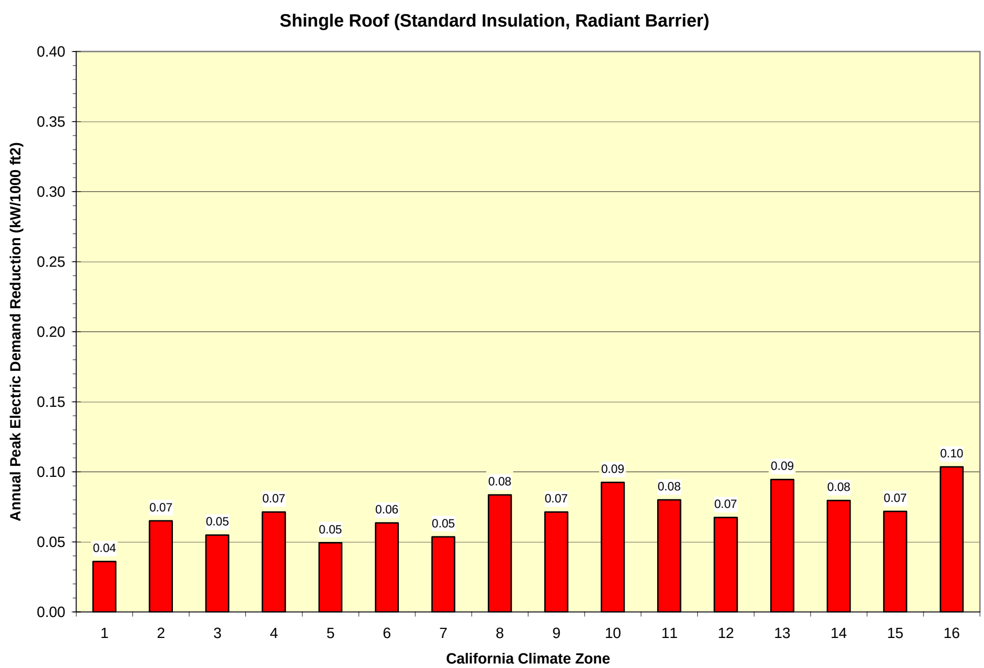
16
California Climate Zone

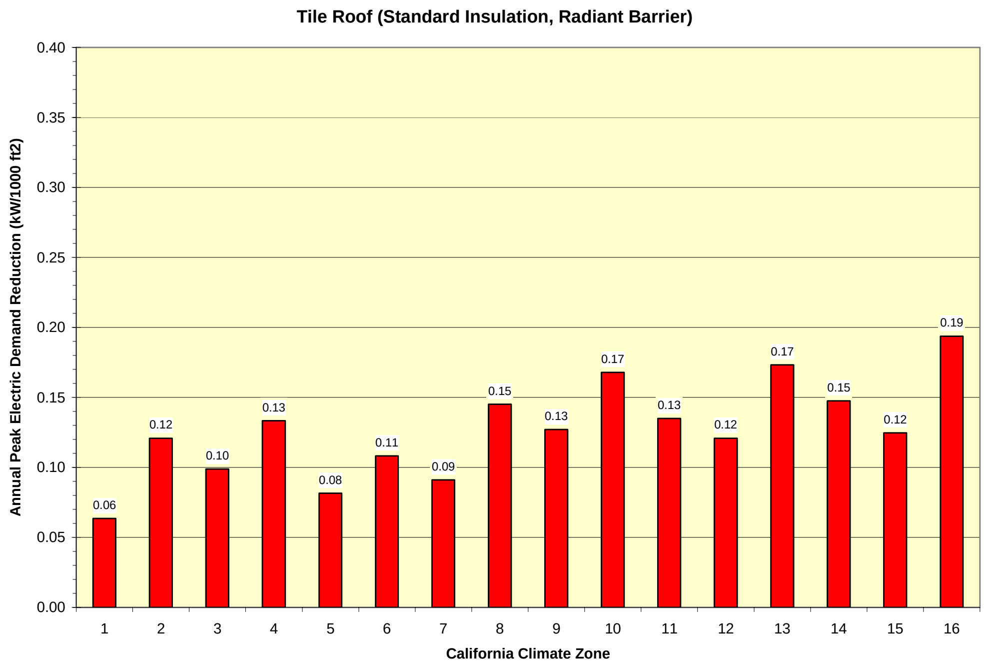
(g)


Flat Built-Up Roof (No Attic Ventilation, No Radiant Barrier)
Annual Peak Electric Demand Reduction (kW/1000 ft2)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.07
0.13
0.11
0.17
0.09
0.10
0.09
0.11
0.11
0.12
0.10
0.10
0.12
0.11
0.11
0.11
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
California Climate Zone

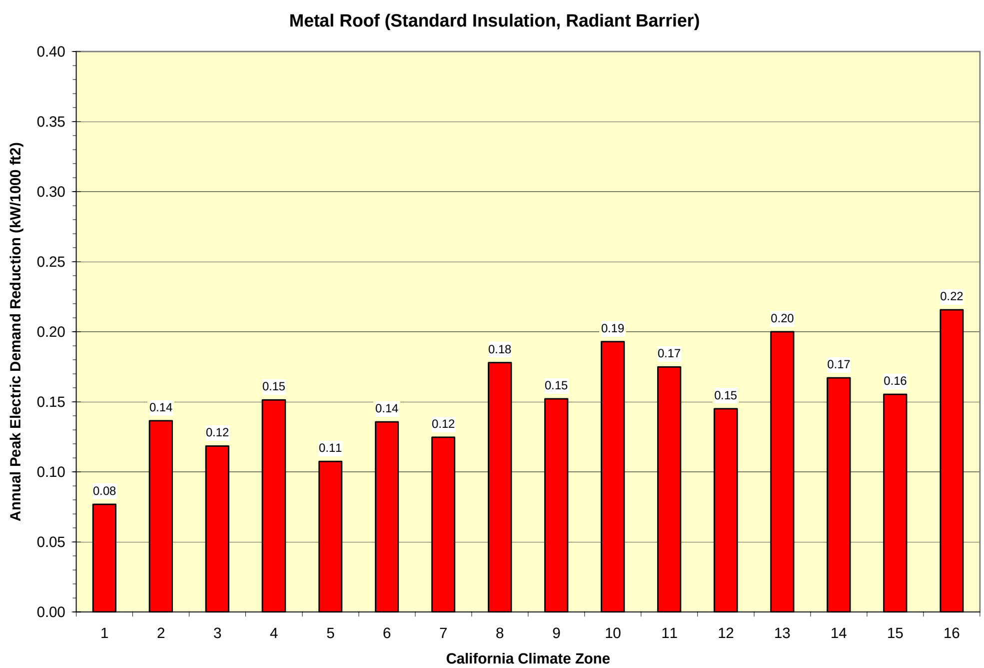
(h)


Shingle Roof (Standard Insulation, Radiant Barrier)
Annual Peak Electric Demand Reduction (kW/1000 ft2)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.04
0.07
0.05
0.07
0.05
0.06
0.05
0.08
0.07
0.09
0.08
0.07
0.09
0.08
0.07
0.10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
California Climate Zone

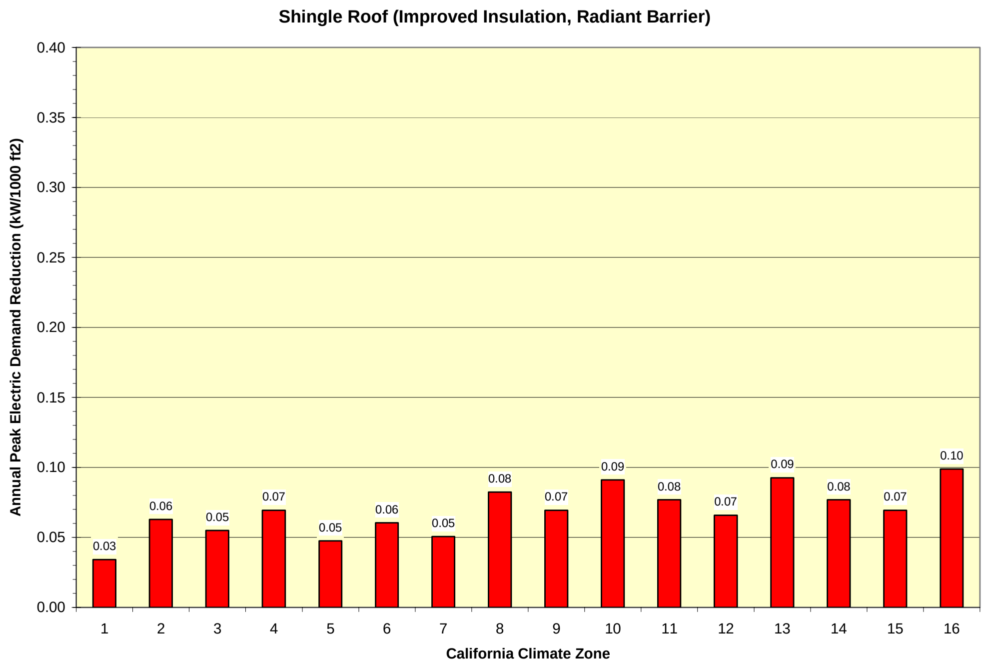
(i)


Tile Roof (Standard Insulation, Radiant Barrier)
Annual Peak Electric Demand Reduction (kW/1000 ft2)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.06
0.12
0.10
0.13
0.08
0.11
0.09
0.15
0.13
0.17
0.13
0.12
0.17
0.15
0.12
0.19
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
California Climate Zone

(j)


Metal Roof (Standard Insulation, Radiant Barrier)
Annual Peak Electric Demand Reduction (kW/1000 ft2)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.08
0.14
0.12
0.15
0.11
0.14
0.12
0.18
0.15
0.19
0.17
0.15
0.20
0.17
0.16
0.22
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
California Climate Zone

(k)



Shingle Roof (Improved Insulation, Radiant Barrier)
Annual Peak Electric Demand Reduction (kW/1000 ft2)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.03
0.06
0.05
0.07
0.05
0.06
0.05
0.08
0.07
0.09
0.08
0.07
0.09
0.08
0.07
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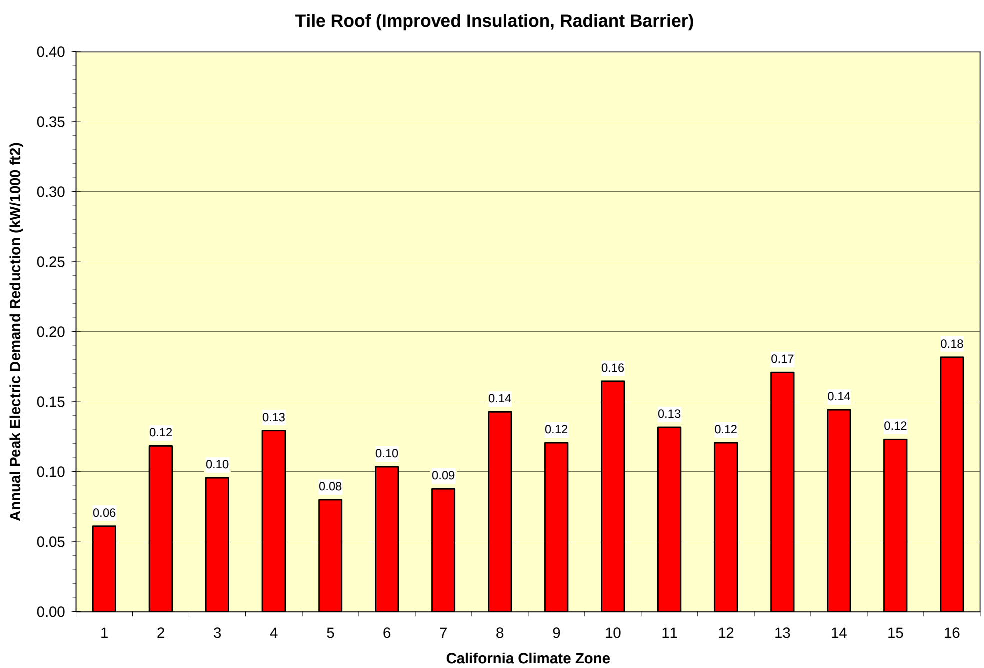
16
California Climate Zone

(l)



Tile Roof (Improved Insulation, Radiant Barrier)
Annual Peak Electric Demand Reduction (kW/1000 ft2)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.06
0.12
0.10
0.13
0.08
0.10
0.09
0.14
0.12
0.16
0.13
0.12
0.17
0.14
0.12
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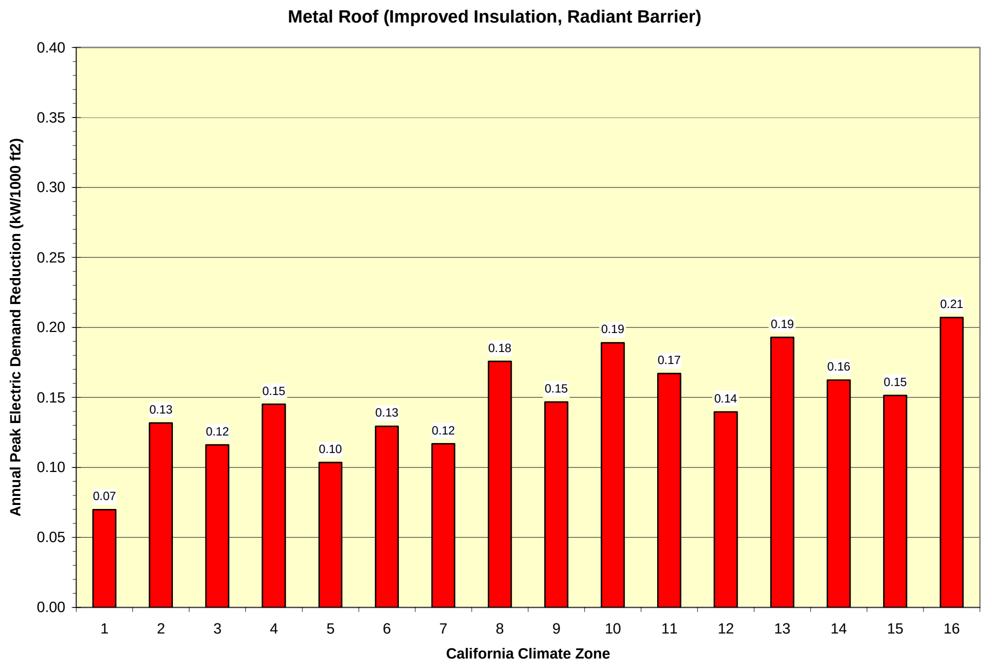
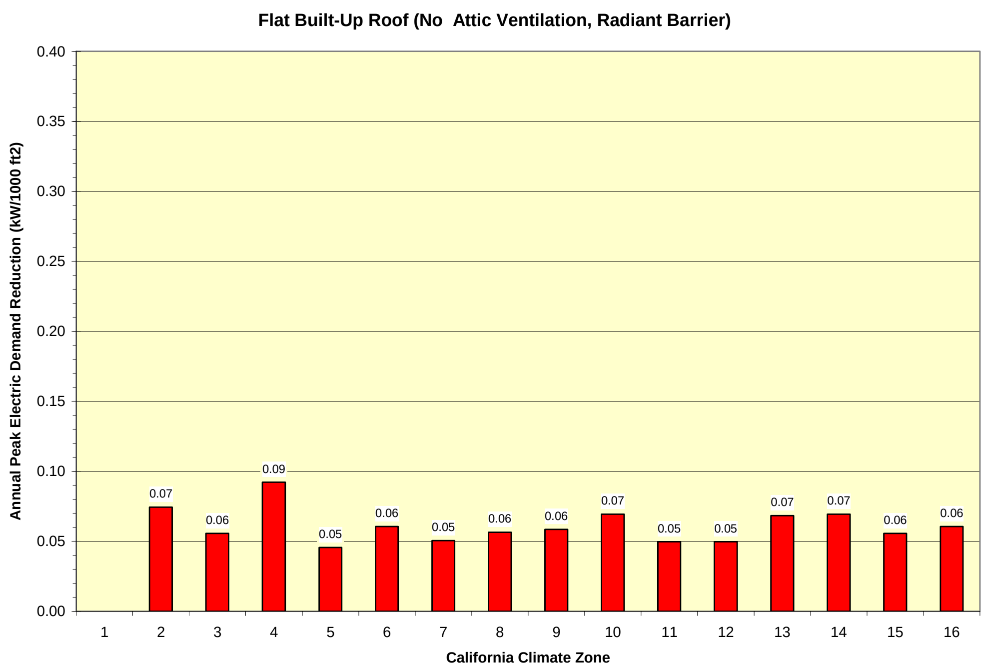
California Climate Zone

(m)

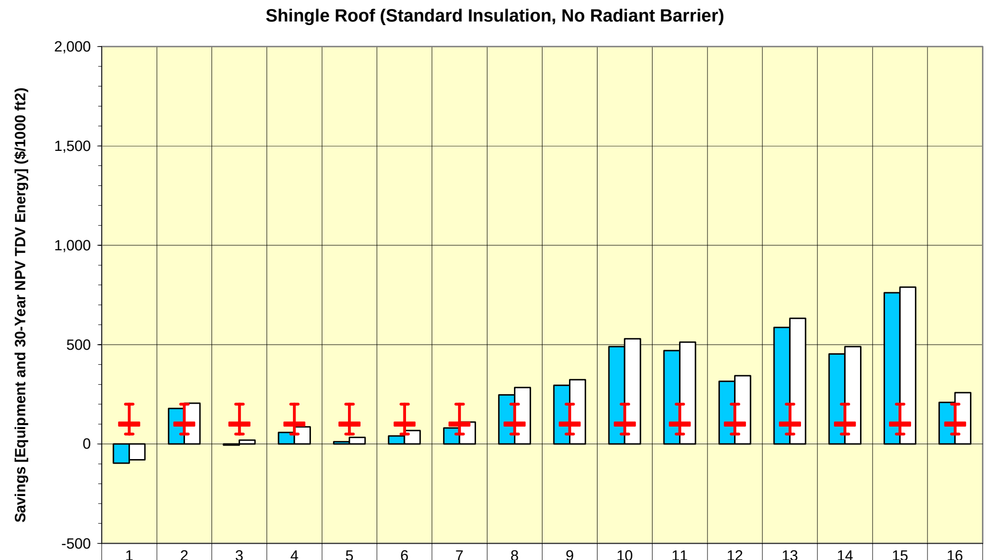

Metal Roof (Improved Insulation, Radiant Barrier)
Annual Peak Electric Demand Reduction (kW/1000 ft2)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.07
0.13
0.12
0.15
0.10
0.13
0.12
0.18
0.15
0.19
0.17
0.14
0.19
0.16
0.15
0.21
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
California Climate Zone

(n)


Flat Built-Up Roof (No Attic Ventilation, Radiant Barrier)
Annual Peak Electric Demand Reduction (kW/1000 ft2)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.07
0.06
0.09
0.05
0.06
0.05
0.06
0.06
0.07
0.05
0.05
0.07
0.07
0.06
0.06
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
California Climate Zone

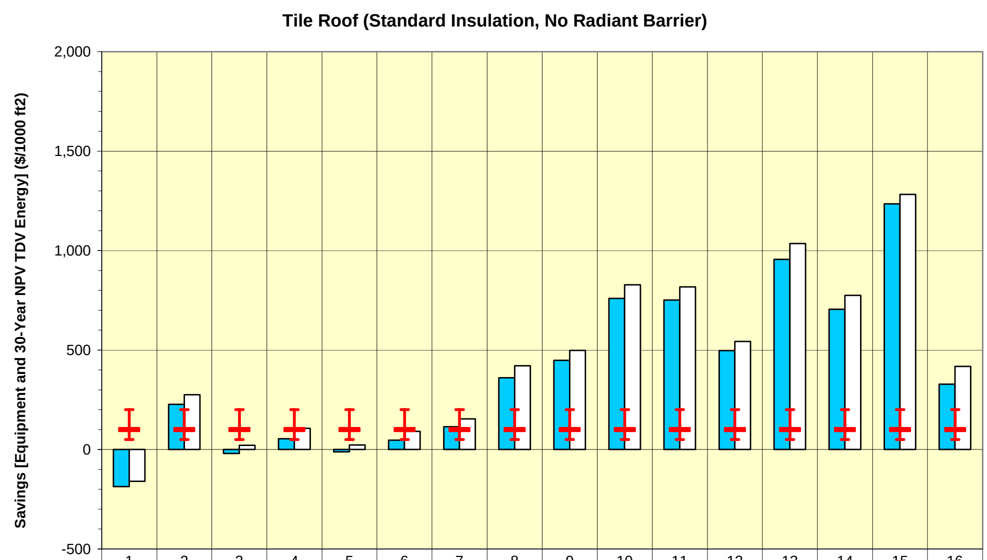
Figures 4a-n. Savings (cooling equipment savings plus 30-year NPV of energy savings) in \$/1000 ft² versus California climate zone, simulated for a prototypical Title-24 building, with time dependent valuation (TDV). Material cost premiums (0.05, 0.10, and 0.20 \$/ft²) are overlaid on the NPV data.

(a)



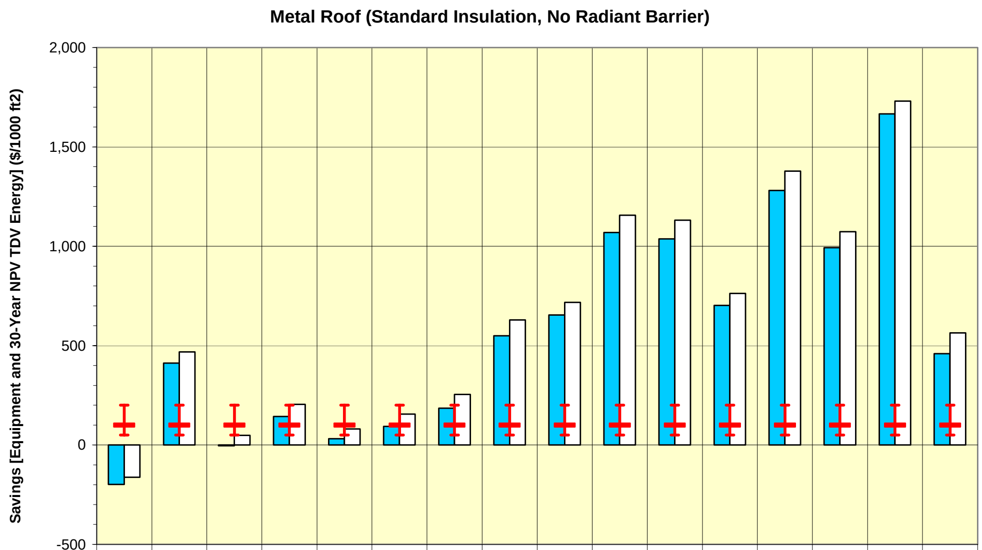
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TDV	-97	179	-5	58	12	40	80	247	295	490	469	316	587	452	761	209
TDV+Equip	-80	206	20	86	34	68	111	284	324	529	512	344	632	490	790	259
$0.10/ft2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

(b)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TDV	-187	227	-20	55	-12	47	114	360	449	760	751	497	956	705	1,235	329
TDV+Equip	-160	275	20	106	22	91	155	421	498	828	817	543	1,035	774	1,282	418
$0.10/ft2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

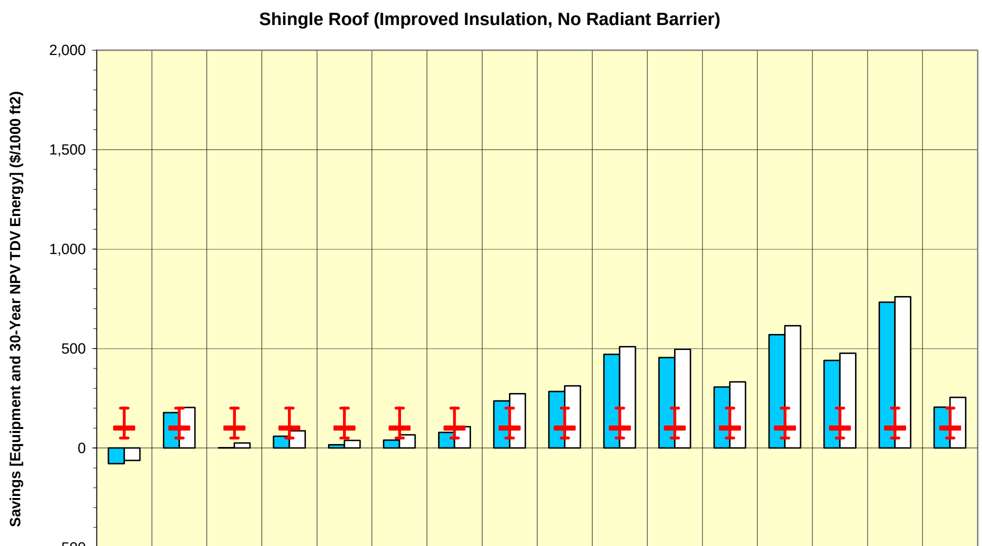
(c)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TDV	-199	412	-4	144	31	94	185	550	654	1,070	1,036	703	1,281	993	1,666	460
TDV+Equip	-162	469	48	205	80	156	254	629	718	1,156	1,131	763	1,378	1,073	1,729	564
$0.10/ft2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

California Climate Zone

(d)

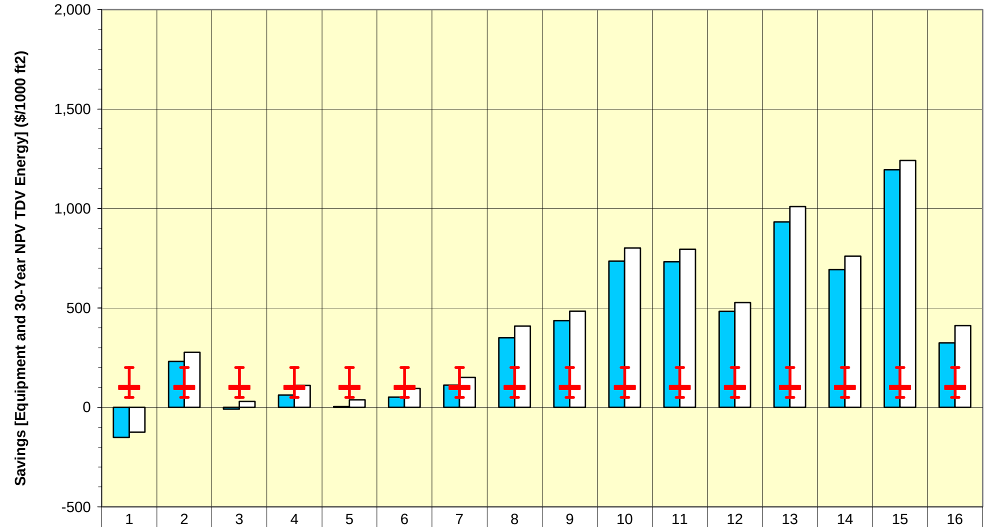


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TDV	-79	178	2	59	17	39	78	237	284	471	455	307	570	440	733	206
TDV+Equip	-62	204	25	87	38	66	107	273	312	510	496	333	614	476	760	254
$0.10/ft2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

California Climate Zone

(e)

Tile Roof (Improved Insulation, No Radiant Barrier)

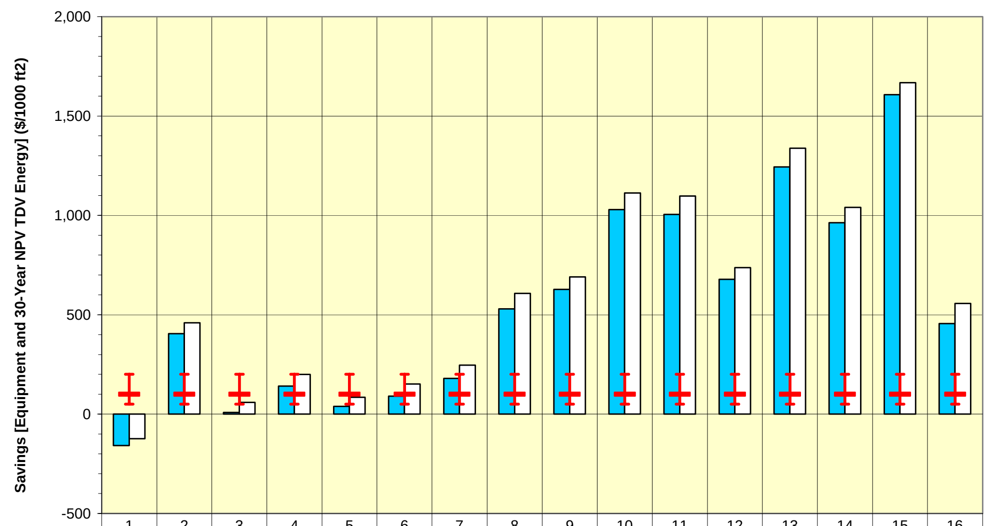


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TDV	-151	232	-8	62	4	52	112	351	436	736	731	483	932	693	1,195	325
TDV+Equip	-124	277	30	111	38	95	151	410	484	802	795	527	1,010	760	1,241	411
$0.10/ft2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

California Climate Zone

(f)

Metal Roof (Improved Insulation, No Radiant Barrier)

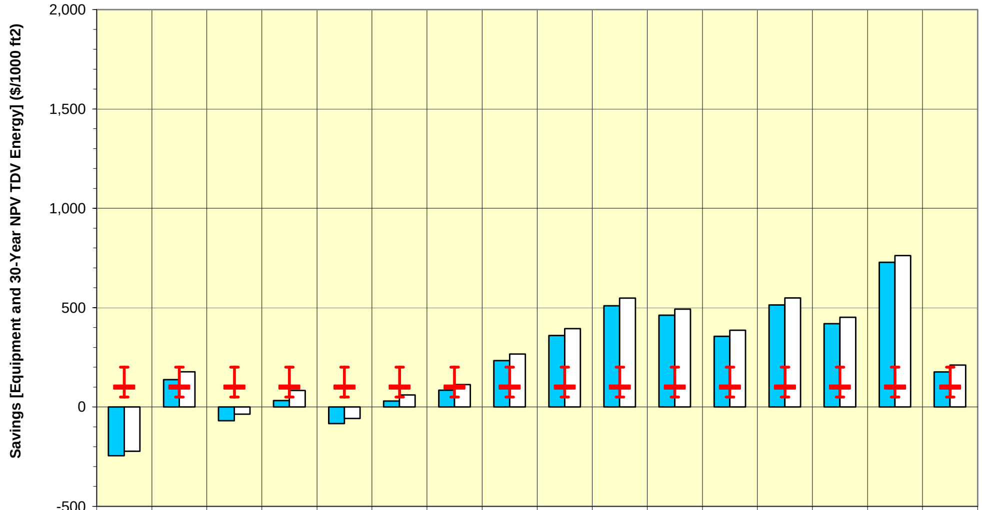


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TDV	-158	405	8	141	39	90	180	529	628	1,029	1,005	679	1,244	963	1,607	455
TDV+Equip	-123	459	59	199	85	151	246	607	690	1,112	1,097	737	1,338	1,040	1,668	557
$0.10/ft2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

California Climate Zone

(g)

Flat Built-Up Roof (No Attic Ventilation, No Radiant Barrier)

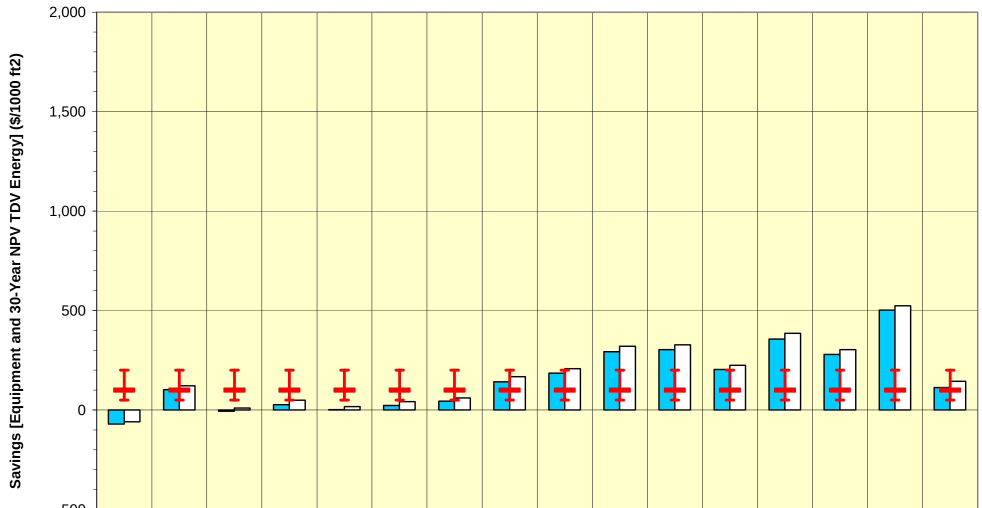


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TDV	-245	138	-69	32	-83	30	85	233	359	510	462	356	513	419	728	176
TDV+Equip	-223	177	-36	83	-57	61	113	266	394	548	493	386	548	451	762	211
$0.10/ft2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

California Climate Zone

(h)

Shingle Roof (Standard Insulation, Radiant Barrier)

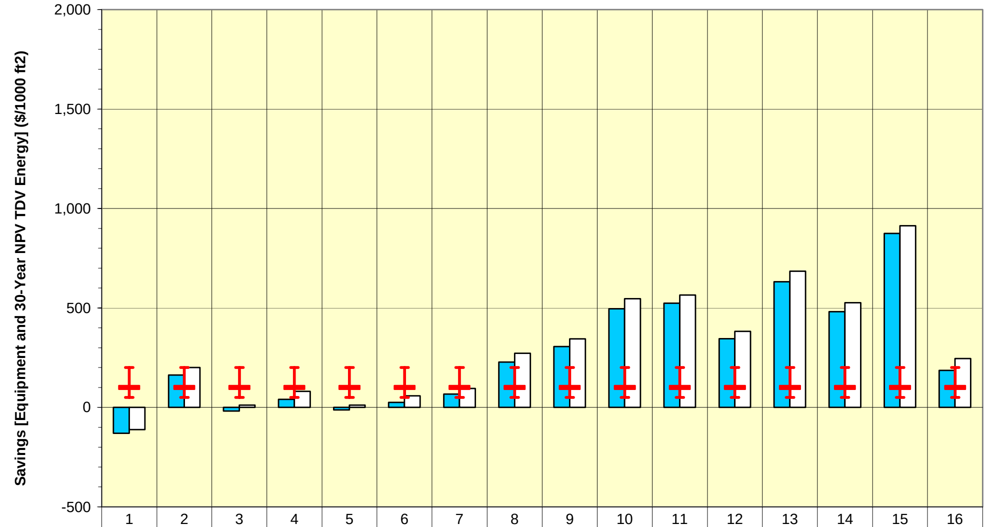


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TDV	-70	102	-6	27	2	23	44	142	185	292	303	204	357	279	502	113
TDV+Equip	-59	122	11	49	17	42	61	167	207	321	328	224	385	304	524	144
$0.10/ft2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

California Climate Zone

(i)

Tile Roof (Standard Insulation, Radiant Barrier)

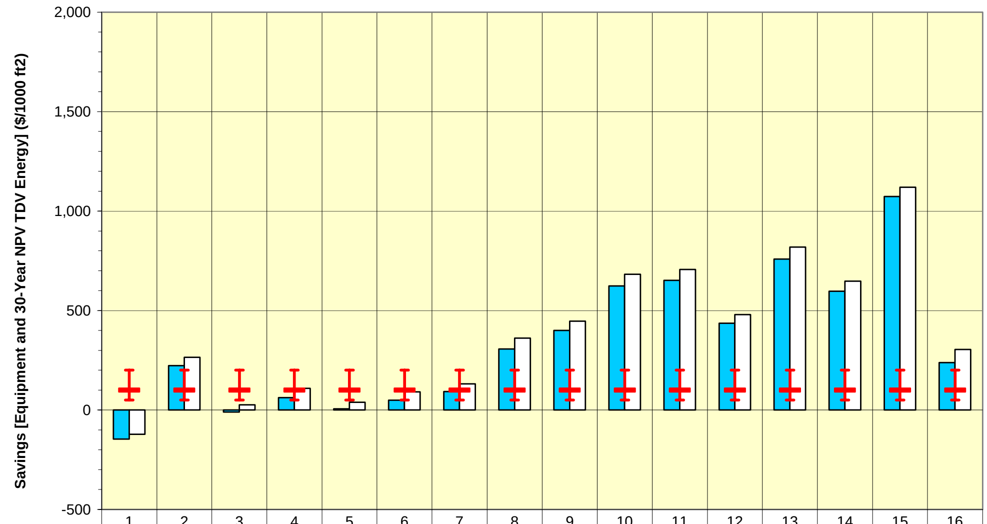


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TDV	-131	163	-18	40	-13	25	67	228	306	495	524	345	631	481	875	186
TDV+Equip	-111	200	12	81	12	58	95	273	345	546	565	382	684	526	913	245
$0.10/ft2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

California Climate Zone

(j)

Metal Roof (Standard Insulation, Radiant Barrier)

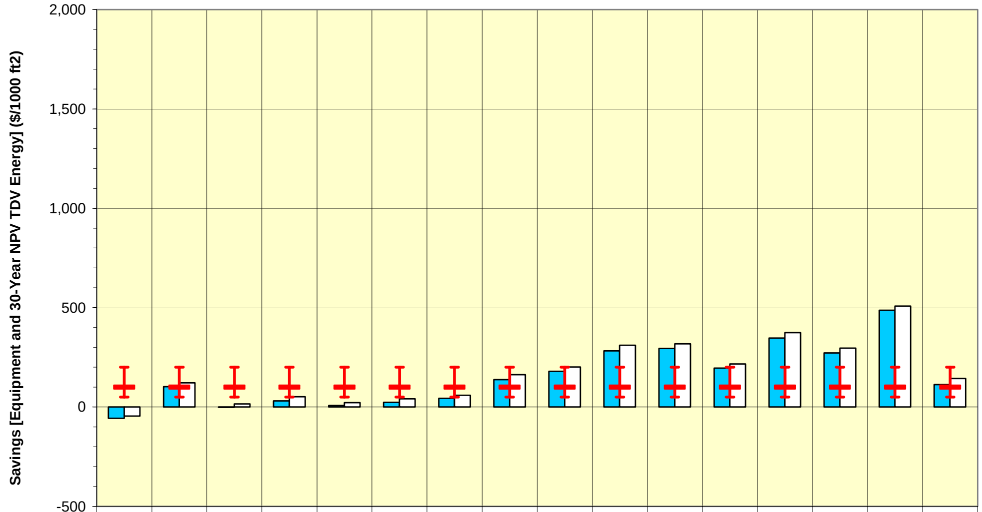


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TDV	-146	224	-10	62	6	49	93	307	400	623	652	435	758	596	1,073	239
TDV+Equip	-123	265	26	109	39	91	131	361	447	682	706	480	819	647	1,120	305
$0.10/ft2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

California Climate Zone

(k)

Shingle Roof (Improved Insulation, Radiant Barrier)

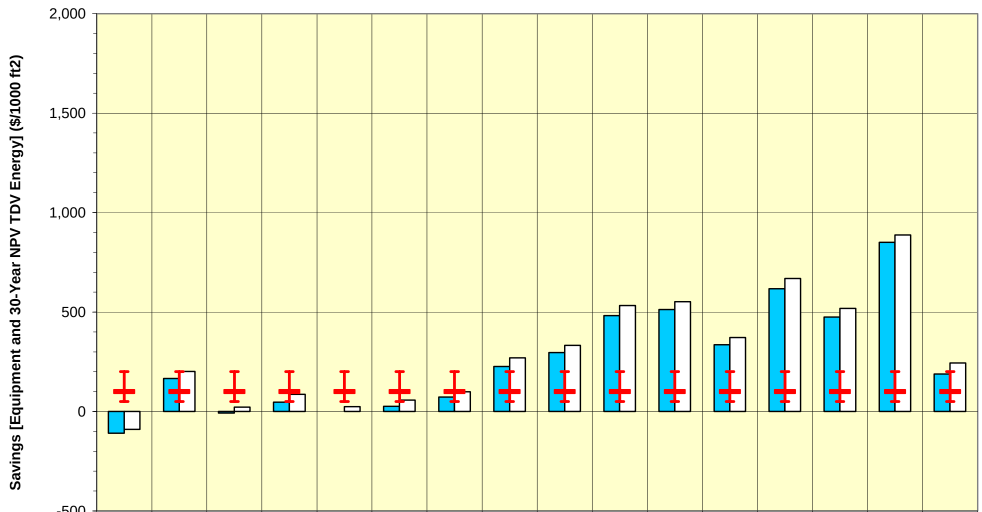


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TDV	-56	103	-1	31	7	23	44	138	180	283	295	196	347	272	486	113
TDV+Equip	-46	122	16	52	22	42	59	163	201	310	318	216	375	296	507	144
$0.10/ft2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

California Climate Zone

(l)

Tile Roof (Improved Insulation, Radiant Barrier)

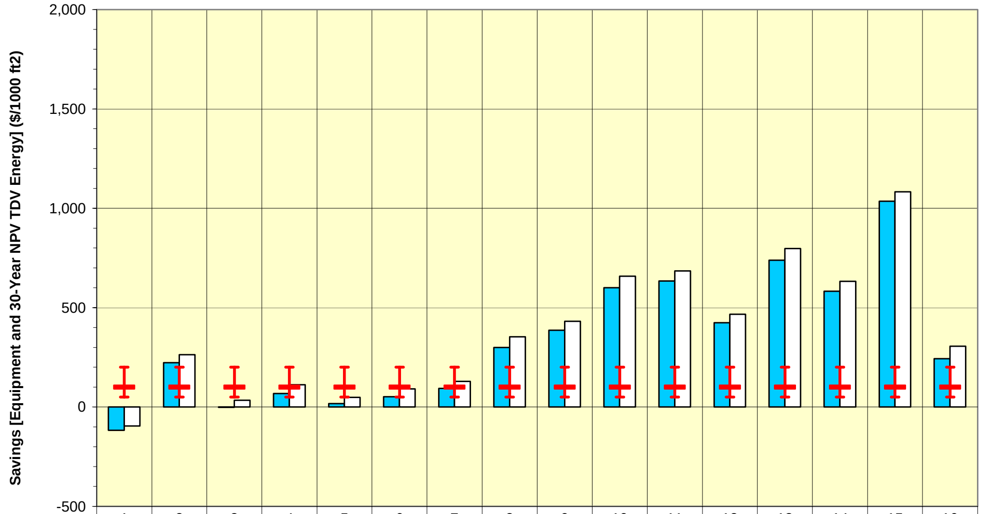


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TDV	-109	165	-8	47	0	26	72	226	296	482	512	335	617	475	850	188
TDV+Equip	-90	201	21	86	25	57	99	270	333	532	552	372	669	519	888	244
$0.10/ft2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

California Climate Zone

(m)

Metal Roof (Improved Insulation, Radiant Barrier)

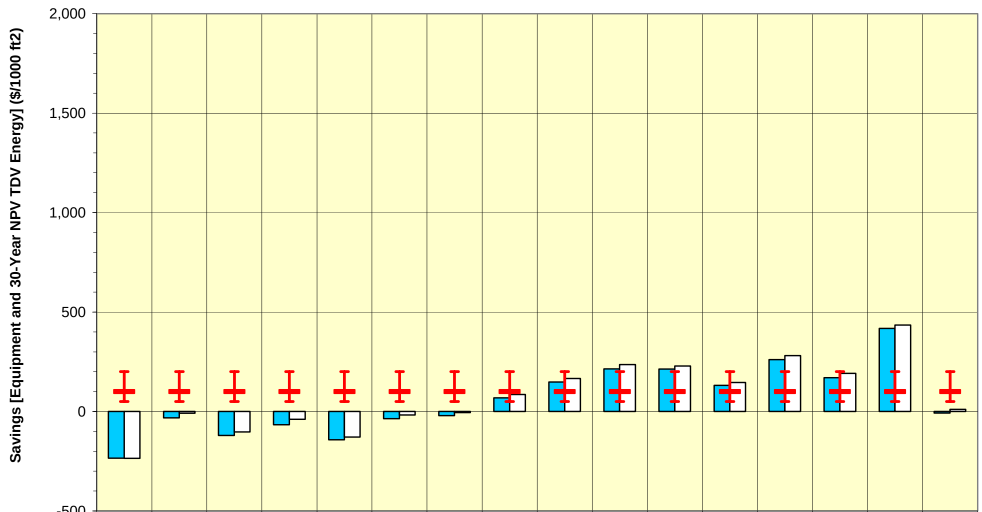


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TDV	-117	223	-1	68	17	51	94	300	386	600	634	424	739	583	1,036	243
TDV+Equip	-96	264	34	112	48	91	129	353	431	658	685	467	798	633	1,082	306
$0.10/ft2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

California Climate Zone

(n)

Flat Built-Up Roof (No Attic Ventilation, Radiant Barrier)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TDV	-234	-32	-120	-67	-142	-36	-21	69	148	214	213	131	261	171	418	-8
TDV+Equip	-235	-9	-103	-39	-128	-18	-5	86	165	236	229	146	281	192	435	11
$0.10/ft2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

California Climate Zone